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The potential of forest floor transfer for the reclamation of boreal forest understory plant communities

by

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To mom and dad, for your unconditional support.

Abstract

We examined a direct forest floor transfer reclamation technique to establish a native boreal forest understory plant community on a reclamation site at a coal mine. Forest floor material was salvaged from an aspen-dominated (*Populus tremuloides* Michx.) donor forest at two depths (15 and 40 cm) and placed at a reclamation site at those same depths. We conducted vegetation surveys at the donor site prior to salvage and at the reclamation site in the first year. The surveys showed that the donor site had a later successional plant community than the reclamation site, which had a recently disturbed / early successional plant community. The 15 cm depth treatments had higher percent cover and species richness than the 40 cm treatment but the species compositions were similar. This reclamation technique shows potential to effectively establish a species-rich native understory forest plant community in the future.

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Chapter 1: Introduction

1.1 Introduction to research area

Around the world, large areas of the landscape are being severely disturbed for the purposes of resource extraction, and especially so for open pit mining. Due to this extensive land disturbance, there have been calls from the public on local and international scales to ensure rapid reclamation to natural ecosystems representative of the area. In Alberta, this is a particularly urgent issue, as open pit oil sands and coal mining activities sometimes remove large tracts of the boreal forest from the land. In Alberta, these mining activities are having the largest impact in the boreal forest area, where all oil sands and much coal mining is carried out. The Alberta government, through the Environmental Protection and Enhancement Act (EPEA), set the goal for mining companies to reclaim disturbed areas to "capable of supporting a self-sustaining, locally common boreal forest" (Cumulative Environmental Management Association, 2009). This involves the use of native species, and necessitates the initiation of an understory plant community as well as the overstory to allow a functioning forest ecosystem to develop. In the boreal forest, understory plant communities are diverse and ecologically important for a variety of reasons, such as their involvement in nutrient cycling and their ability to provide food and shelter for forest fauna (Yarie 1980; Halpern and Spies 1995; Whittle et al. 1997;

Macdonald and Fenniak 2007). Understory communities are challenging to reclaim. Perhaps the largest challenge is the difficulty in obtaining native understory plant propagules. The seeds of native understory plants are not commercially available for sale, and collection of native understory seed is very time consuming and not a realistic solution for carrying out reclamation at an operational scale (Mackenzie and Naeth 2007; Macdonald et al. 2011). Further, little is known about the autecology of native understory plants and conditions required for them to successfully germinate and thrive, or about the use of greenhouses to provide plants for reclamation (Harrington et al. 1999; Mackenzie and Naeth 2007; Macdonald et al. 2011). Another substantial challenge includes a lack of knowledge about the interactions between the canopy, understory, and the soil (Macdonald et al. 2011). Considering the importance of understory plant communities to the proper functioning of a boreal forest ecosystem, it is important that research into reclamation techniques for these communities is undertaken.

The dry mixedwood natural subregion

In Canada, the boreal forest covers 35% of the land and represents 77% of the total forest in the country. The boreal is the largest natural region in Alberta, occupying the northern portion of the province (Heritage Community Foundation 2011). It is comprised of a mosaic of plant communities, dominated by conifer trees such as spruce, fir, larch, and pine, and some deciduous trees like aspen, birch and balsam poplar (Natural Resources Canada 2009).

There are many challenges associated with reclamation in the dry mixedwood natural subregion of Alberta. Forests, mostly aspen-dominated, naturally cover this area (Natural Regions Committee 2006). However, this area has been vastly impacted by human activities, primarily by the expansion of agricultural land and by industrial activities such as coal mining. To date, most reclamation activities in this area had aimed to reclaim land to agricultural uses. However, as there has been a push from the Alberta government to reclaim to more natural ecosystems, there is an increasing need for information about how to reclaim disturbed lands in this area to systems that more closely resemble natural forests. This is especially challenging in this region of the province as the landscape has been converted to agricultural land, which has resulted in few natural sources of native forest plant propagules left in the region. In addition, the climate creates another challenge in this area, as this is the driest and warmest end of the spectrum that can support boreal forest ecosystem types (Natural Regions Committee 2006).

1.2 Overview of natural recovery after a disturbance in the boreal forest

Definition of a plant community

A plant community is an assemblage of many different species of plants and is characterized by their spatial and temporal relations to each other, as well as their relationships with other factors that are part of the ecosystem to which they belong (Watt 1947). Interactions can occur between the plants and other biotia, such as herbivores or soil fauna, or with abiotic factors such as the microclimate or soil nutrients. These interactions vary over time and are key to the process of plant community recovery after disturbance. An understanding of the interactions and processes involved in plant community recovery after disturbance is important for reclaiming forest plant communities because natural processes could be emulated or facilitated by reclamation practices.

Summary of natural recovery after a disturbance

After a natural disturbance occurs in a forest, the plant community goes through a series of somewhat predictable steps of recovery. Immediately after a disturbance occurs, seeds and vegetative buds in the soil seed and bud bank that have survived the disturbance have the potential to germinate or to resprout. These seeds have been added to the seed bank through sexual reproduction of plants currently on the site, plants adjacent to the site that dispersed in, or plants that were on the site in the past and have long-lived seeds. The buds will be present from vegetative reproduction of plants that were present in the area prior to the disturbance. Given a certain pool of potential reproductive propagules, the microsite conditions will have a large influence over which species germinate from the seed and bud banks. Abiotic factors such as moisture, light, temperature, nutrient availability, organic matter, soil pH, and microsite heterogeneity will determine which species are able to germinate at a particular time and place. The germinants must then acquire nutrients for growth; nutrient availability is a function of litter quantity and quality, the decomposition activities of soil microorganisms, nutrient cycling, and activities of nitrogen-fixing bacteria. Mycorrhizae also facilitate plant uptake of nutrients. When plants are able to acquire the resources that they need, they can enter the recruitment phase of plant community recovery, which is the addition of new plants into the community (Ribbens et al. 1994). Finally, the forest will continue to develop through individual plant growth and given enough time, the disturbed area can redevelop to mature forest until another disturbance resets succession.

The importance of the bud bank and seed bank

Within the forest floor, there is a collection of buds – undeveloped vegetative tissues with the potential to reproduce vegetatively. The bud bank has the potential to provide propagules from the forest floor for regeneration after a disturbance (Schimmel and Granström 1996). The seed bank is the pool of viable seeds buried in the soil. It is ecologically important for the regeneration of a boreal forest as it represents a significant and potentially diverse source of seeds for development of the future forest community (Greene et al. 1999). The annual seed rain, along with germination, death, and predation rates in an area determine the abundance and composition of the seed bank (Harper 1977). The species present in the seed bank after a disturbance will depend upon pre-disturbance species composition in the seed bank, the severity of the disturbance, and the amount of time since the last disturbance (Greene et al. 1999). There can be a massive number of seeds, representing many different species, buried in a small amount of soil – some of which may not be present as plants in the area. Most of the seeds present in the seed bank are in a state of dormancy (Zasada et al. 1992).

Seed dormancy is a stage in the development of a seed in which metabolic activity slows down significantly – the seed enters a period of rest. Dormancy is important for seed survival because it serves as a protective mechanism to ensure that not all seeds of a species germinate and die in unfavourable conditions (Zasada et al. 1992). Genetics, along with environmental conditions determine when a seed will break dormancy and germinate (Finch-Savage and Leubner-Metzger 2006). Some of the environmental conditions that signal a seed to enter or exit a state of dormancy include light, temperature, temperature fluctuations, and available water in the soil (Schütz 2000). For example, in a study of 32 *Carex* species, many species of which are present in the northern boreal forest, it was found that 58% germination occurred when the seeds were exposed to light, and only 14% germination occurred in the dark, demonstrating that light was an important factor to break dormancy in *Carex sp*. (Schütz and Rave 1999). The regeneration niche of the species defines the conditions under which a seed will leave its stage of dormancy and eventually establish on a site (Grubb 1977). The particular conditions that are suitable for some species could be unsuitable for others, which is why some seeds from the seed bank germinate under specific conditions while others do not (Grubb 1977; Finch-Savage and Leubner-Metzger, 2006). Lengths in dormancy can vary greatly amongst species, but some seeds present in the seed bank can maintain their state of dormancy for many years until conditions are suitable for them to germinate (Finch-Savage and Leubner-Metzger 2006). For example, in a study that has been going on for over 120 years, 32 seeds of moth mullein (*Verbascum blattaria* L.) were still viable after being dormant in the seed bank for the entire 120 year period (Telewski and Zeevaart 2002). In the boreal forest, paper birch is the only tree species that has a dormancy period longer than 9 months (Greene et al. 1999). However, *Calamagrostis canadensis* (Michx.) P. Beauv., a common boreal forest understory species, has been reported to remain dormant in the seed bank for over 20 years (Conn and Farris 1987), and the seeds of the early successional boreal forest shrub *Prunus pensylvanica* (L.f.) can remain dormant in the seed bank for over 30 years (Marquis 1975).

The ability of seeds to remain dormant in the seed bank is an important component in the recovery of a forest after a natural disturbance. After a disturbance such as a fire, the forest relies upon plants to regenerate either from seeds that were dormant in the seed bank, or vegetative reproduction from the bud bank (Granström and Schimmel 1993). However, it is also possible that an intense disturbance may destroy the seeds in the seed bank, and thus, dispersal is also an important process in the regeneration of Canadian forests (Granström and Schimmel 1993).

Seed dispersal, re-colonization, germination, and recruitment

Dispersal is the manner in which a plant distributes its offspring within a landscape through space and time. Dispersal can occur asexually through the growth of new ramets, or sexually through the movement of seeds. Seed dispersal can occur via wind, animals, or water (Johansson et al. 1996). The seeds of all boreal forest trees are dispersed primarily via wind, and the dispersal distance depends upon tree height, horizontal and vertical wind velocities, and seed mass (Greene et al. 1999). Animal dispersal is also important. For example, pin cherry (*Prunus pensylvanica*), a northern boreal shrub species, relies upon birds to eat its fruits and seeds, then pass the seeds through its digestive system in order to disperse the seeds of this shrub (Stiles 1980). Dispersal is important in the regeneration of forests after a disturbance because if the disturbance was very intense, for example a severe fire, the seed bank may have been destroyed in the fire. In this situation, dispersal is vital for new seeds and plant propagules to re-colonize the area that has been disturbed and commence the regeneration of the plant community (Granström and Schimmel 1993).

After a disturbance occurs and seeds have dispersed into the disturbed area, conditions must be favourable in order for seeds to germinate and begin the forest regeneration process. When seeds receive the proper environmental cues that they will have a reasonable chance of surviving (for example, sufficient light is available, the O_2:CO_2 ratio in the soil and temperature are favourable for that seed, etc.), they leave the dormancy stage and begin the germination process (Baskin and Baskin 1985).

If seedlings survive the germination stage, they enter the recruitment phase of the reproductive cycle of plants. Recruitment is the development of a seed into a seedling, and it occurs when a seed germinates and "is able to survive without maternal resources" (Ribbens et al. 1994). It has been found in the Canadian boreal forest that the successful recruitment of trees after a fire is dependent upon appropriate microsite conditions, which can vary by species. For white spruce (*Picea glauca* (Moench) Voss), a boreal forest conifer species, recruitment microsites were found to have a high cover of downed wood and moss and a lower cover of litter and herbaceous vegetation, and the seedbed type was often a limiting factor for recruitment (Purdy et al. 2002; Wang and Kemball 2005). White spruce can most successfully recruit on mineral soil or humus seed beds, while rotten logs also provide suitable microsites for recruitment of this species (Wang and Kemball 2005; Peters et al. 2006). The overstory type can also have an effect on recruitment, as Wang and Kemball (2005) found that balsam fir (*Abies balsamea* (L.) Mill.) was more successful at recruitment under aspen stands than white spruce was. An important challenge for reclamation is to provide the appropriate microsites for plants to recruit and survive.

1.3 Reclamation

Land reclamation is the process by which environments that have been severely disturbed by human activities, such as mining, are restored to ecosystems that meet a specific use. Uses for reclaimed land include a broad range of possibilities, such as forestry, agriculture, recreation, habitat conservation, etc. Forest ecosystems are very complex and dynamic systems and this poses an immense challenge for reclamation. Reclaiming a forest in the boreal mixedwood is an exceedingly complicated undertaking and requires substantial knowledge about the interactions and processes that occur in natural forest regeneration. Knowledge of the natural recovery process of a forest can be applied to the process of restoring a forest that has been anthropogenically disturbed.

History of reclamation in Alberta

Reclamation is particularly important in Alberta, where conventional oil and gas, coal mining, and oil sands mining activities have had a large impact upon the natural landscape. To date over 1,800 coal mines are known to have operated in the province of Alberta. In 2008, Alberta produced 32.5 million tonnes of marketable coal, and coal mines supplied 59% of the province's electricity (Government of Alberta 2011). Oil sands mines are a more recent development in Alberta, but are quickly having a more extensive impact on the natural environment. In 1964 the first oil sands mine, Great

Canadian Oil Sands (now Suncor Energy Inc.) began mining north of the town of Fort McMurray. Since then, the industry has expanded to include several more major mines, and 602 km^2 of land has been disturbed by oil sands mining activities, with much more predicted for the future (Government of Alberta 2011). Although the research described in this thesis focused on reclamation of an area surface mined for coal, the reclamation technique and knowledge gained from the research could be applied to any of the mining activities that occur in the boreal forest regions of Alberta and beyond.

Due to the large area of land that mining disturbs and the aesthetically displeasing landscape that surface mining creates, these mines attract much attention from the public, media, and the government in Alberta. Effective reclamation practices are being called for from all sectors, and are required by Alberta law. In 1993, the Government of Alberta created the Environmental Protection and Enhancement Act, under which mines may only operate under their specific operating approvals (Government of Alberta 2011). These approvals state that the goal of reclamation must be "to achieve land capability equivalent to that which existed prior to disturbance" (Alberta Environment 2006) and that the reclaimed landscape should be "capable of supporting a self-sustaining, locally common boreal forest" (Cumulative Environmental Management Association, 2009).

To meet government requirements, mining companies have been carrying out reclamation activities and research into new reclamation methods for many years. The use of stockpiles to store surface soil and overburden is a common practice in reclamation, and most reclamation projects use material that has been stored in stockpiles for many years (OSVRC 1998; McMillan et al. 2007). The viability of the seeds in these stockpiles is very low, necessitating seeding and planting for all plant species that are desired on the reclaimed site (MacKenzie and Naeth 2009). The use of stockpiled forest floor material is now known to be a less than ideal practice for achieving regeneration of natural plant communities, and operations that do not require the use of stockpiling and seeding could be more effective in achieving a natural-like forest.

In 1998, the Oil Sands Vegetation Reclamation Committee (OSVRC) created a document that outlined guidelines for the reclamation of forests in the Athabasca Oil Sands Region. These guidelines are widely followed by industry when undertaking reclamation. The guidelines outline different types (e.g. peat-mineral mix) and depths (e.g. 15 to 50 cm) of soil caps that can be used to cover overburden in reclamation. The purpose of the soil caps is to achieve an appropriate soil capability rating to facilitate soil development and plant community establishment at reclamation sites. The use of cap type and depth depends upon the properties of the underlying material, with material that could have more adverse effects upon vegetation requiring the thicker cap application depths (OSVRC 1998).

Rowland et al. (2009) conducted a study to investigate the outcome on sites reclaimed with either subsoil or a mixed peat-mineral soil cap. They found that there were varying degrees of success in establishing natural-like ecosystems. They report that the most successful reclamation technique involved using a peat-mineral mixture as a soil cap and repeatedly fertilizing. However, they found that the reclaimed sites in their study were not achieving the same productivity as natural forests. This conclusion led to the realization that there was a need for an improved method for reclaiming forests.

Recently, forest floor material (sometimes also referred to as LFH), which consists of the upper mineral soil horizons and the top layer of the forest floor, [made up of the litter, fermenting litter, and humus layers (Paré et al. 1993)] has been suggested as a capping material for reclamation (Mackenzie and Naeth 2007). The main benefit of using the forest floor material for reclamation, rather than the traditional subsoil or a peat-mineral mixture, is that the forest floor material can provide a diverse source of propagules for re-establishment of vegetation in reclaimed lands (Mackenzie and Naeth 2009). A study by Mackenzie and Naeth (2009) at a reclaimed site in the Athabasca Oil Sands Region concluded that forest floor was a better substrate than peat for the establishment of a successful upland vegetation community. This conclusion was based on the higher species richness and abundance at sites reclaimed with forest floor material. Additionally, it was found that this material provided more available nutrients for plants, along with a source of appropriate upland native plant propagules (as compared with the peat-mineral mix that contained plant propagules better adapted to wetter lowland sites). However, research into the use of this material as a reclamation tool has found that if this material is stockpiled for as little as ten months, the viability of the propagules within the material significantly decreases (Iverson and Wali 1982; Koch et al. 1996; Rokich et al. 2000; Mackenzie and Naeth 2009). Therefore, this material could be much more useful in transferring native propagules to reclamation sites if it is not stockpiled so that the propagules can maintain their viability. In addition, the operational reality of using forest floor as a capping material is still in question. The equipment required to carry out this process at an operational scale is very large, and the limited studies that have attempted to use full-sized equipment have reported serious limitations with both the salvage and placement procedures (Koch et al. 1996; Mackenzie and Naeth 2009). It is for this reason that further research into direct placement, or forest floor transfer, is required to determine how to best carry it out at an operational scale, and to better understand the potential ecological advantages of the method.

Specific goals of reclamation have evolved over time as research reveals more information about how ecosystems function and respond to different types of treatments. The overall goal, however, has remained the same: to return disturbed areas to a more natural state. To date, reclamation research was conducted on individual ecosystem components such as proper management of the soil properties (Zvomuya et al., 2009) or soil type (McMillan et al., 2007; Rowland et al., 2009) but did not acknowledge the interconnectedness of the components and how they interact in the ecosystem. However, researchers have begun to recognize the importance of looking at the ecosystem as a whole and this has led to greater interest in establishing understory vegetation in a forest. The understory is the most diverse vegetative component of the boreal forest (Halpern and Spies 1995). It provides food and habitat for other forest organisms and it plays a large part in nutrient cycling and other ecosystem processes (Yarie 1980; Whittle et al. 1997; Macdonald and Fenniak 2007). The use of forest floor material in reclamation could help to re-establish a more "natural" forest ecosystem. The use of forest floor as a means to examine the forest ecosystem as a whole recognizes that the goal of a reclamation project should not only be to serve one human purpose (for example, to reclaim to agricultural land), but instead that reclaiming to a functional forest ecosystem can provide a wide variety of ecological goods and services from which humans and other organisms can benefit.

Current forest reclamation research

Current research in forest reclamation has aimed at addressing these challenges. It is known that successful reclamation may rely on the ability to introduce viable native plant propagules to the reclamation site, and to provide the propagules with appropriate soil moisture and nutrient conditions (Mackenzie and Naeth 2009). To achieve this, researchers have tested the use of forest floor material on reclamation sites, with promising results. However, further research into the use of forest floor material has revealed that stockpiling it causes the viability of the propagules to decline drastically (Iverson and Wali 1982; Koch et al. 1996; Rokich et al. 2000; Mackenzie and Naeth 2009). Therefore, researchers have come up with the idea of the transferring the forest floor directly to a reclamation site (also called direct placement) to avoid stockpiling the material and losing so many propagules. This method involves the stripping of the forest floor material at a donor site (a site which is slated to be mined in the near future). The material is then immediately transferred to the reclamation site where it is spread. The material does not spend any time in a stockpile, and therefore the plant propagules contained within the forest floor material remain viable and can provide a source for native plant growth on the reclamation site. What is still unknown about the forest floor transfer method is how best to carry out the procedure operationally and the potential for ecological gains at reclamation sites.

So far this technique has seen some limited testing in other regions of the world. Iverson and Wali (1982) carried out a study in North Dakota, and Holmes (2001) carried out another in South Africa. Both studies pointed to the potential for success in transferring viable plant propagules to the reclamation site. Some direct placement studies carried out in the Jarrah forest region of western Australia led to the conclusion that the direct placement method is a feasible technique to re-establish a functional forest understory plant community (Tacey and Glossop 1980; Koch et al. 1996; Rokich et al. 2000).

Despite the research that has been carried out in other areas of the world, very little research into direct placement has occurred in Canada. Mackenzie and Naeth (2009) pioneered some studies on using forest floor material in the Athabasca Oil Sands Region, but there is still a large gap in knowledge about the potential for the forest floor transfer reclamation method in Alberta.

Perhaps the largest unknown about the direct placement technique is the depth at which to salvage and place the forest floor material. The salvage depth is important because the propagule bank declines in abundance and diversity with increasing depth in the forest floor (Tacey and Glossop 1980; Iverson and Wali 1982; Putwain and Gillham 1990; Grant et al. 1996; Rokich et al. 2000; Mackenzie and Naeth 2009). Therefore, the depth to which the forest floor is salvaged will influence the propagule pool that is transferred to the reclamation site. The placement depth is just as important as the salvage depth, as seedlings from most species emergence best from a maximum burial depth of 5 cm, although the ideal burial depth for emergence of many species is less than 2 cm (Putwain and Gillham 1990; Grant et al. 1996; Rokich et al. 2000). Therefore, the depth at which the forest floor material is placed will influence seedling emergence at the reclamation site.

Although some studies have investigated the effects of placement depth on reclaimed communities, most studies have found no effect or conflicting results with respect to the effects of application thickness on species richness and seedling density in reclaimed areas (Pinchak et al. 1985; Zhang et al., 2001; Bowen et al. 2005). Further, in these studies the placement depth was not consistent with the salvage depth. In some previous studies, material was salvaged at one depth and mixed together and then spread at a variety of application thicknesses. There could be an effect on reclamation success based on the depth that material is salvaged from rather than the depth that it is placed at. Therefore, we wanted to examine the issue of salvage and placement depth for the forest floor transfer method.

1.4 Objectives

The overall objective of the research presented in this thesis was to evaluate the effectiveness of the forest floor transfer technique on establishing an understory plant community on sites being reclaimed after an industrial disturbance (coal mining). This also included assessing the effectiveness of two different forest floor salvage and placement depths for the directly placed forest floor material.

In Chapter 2 I present results of a study that was designed to examine the potential of the donor site as a source of understory plant propagules for regeneration at the reclamation site. In particular, the aboveground vegetation and the seed bank at the donor site were characterized. Based on this, the species composition of the donor site was compared with the species composition found at the reclamation site after the first year of growth to determine similarities and differences in species compositions.

In Chapter 3 I present the results of the depth study, which included characterizing and comparing the understory species compositions of the two depth treatments to determine which was more effective at establishing a functional understory forest plant community.

In Chapter 4, the final chapter, I summarize my most important findings, analyze the strengths and weaknesses of this study, and provide suggestions for management as well as directions for future research into the forest floor transfer method.

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Chapter 2: The potential of forest floor transfer for the reclamation of boreal forest understory plant communities

2.1 Summary

At a coal mine in central Alberta, Canada, a “forest floor transfer” reclamation project took place in which forest floor material was salvaged from a native aspen forest and immediately placed on a reclamation site. The objective of this study was to assess the donor site as a source for understory plants and evaluate the impact of transfer onto a reclamation site. Vegetation surveys were conducted at the donor site prior to salvage to assess species composition and the seed bank was characterized from forest floor samples. Plant composition was determined at the reclamation site after the first growing season. Results indicate that the donor site was dominated by later successional species, while the species composition at the reclamation site contained more ruderal and non-native species. Approximately 44% of the native species present at the donor site were not found at the reclamation site. However, there were 32 species “gained” at the reclamation site, 18 of which were native, 14 that were non-native. The results of this research show that direct placement of forest floor is a feasible option to augment the establishment of an understory plant community on reclamation sites. However, the data from this study represents only the first year of growth on the reclamation site, and results are expected to change in subsequent years.

In future studies, it may be beneficial to quickly establish a tree canopy on the reclamation site to speed up the process of succession by shading out ruderal species and allowing later successional species to grow without competition from ruderals.

2.2 Introduction

As demand for resources continues to surge around the world, so too does the disturbance of land to mine these resources. In recent years, the need for land reclamation or restoration has become more and more urgent as more natural areas become disturbed for the purposes of mining resources or land development. It is important for land to be restored to a more natural state once the disturbance has ceased in order to conserve natural landscapes and biodiversity. Biodiversity in communities increases ecological stability and creates more resilient communities (Tilman 1996). High quality reclamation projects that preserve native species are vital to conserve biodiversity and the resiliency of natural communities.

While there has been considerable research into reclamation of forests in the past (Zasada et al. 1987; Renault et al. 2000; Shepperd and Mata 2005), relatively little research has focused on the re-establishment of forest understory plant communities. The forest understory plant community is important to reclaim, as it provides erosion control, food for animals, and often holds the bulk of plant species richness and diversity (Whittle et al. 1997). One challenge of re-establishing forest understory communities is the difficulty of obtaining native understory plant propagules (Mackenzie and Naeth 2007; Macdonald et al. 2011). There is also limited knowledge about the autecology and conditions required for the collection of seeds, as well as the germination and survival or possible greenhouse propagation of native understory plants (Harrington et al. 1999; Mackenzie and Naeth 2007; Macdonald et al. 2011). Seeds of native understory plants are generally not available for commercial sale, and seed collection can be very time-consuming and difficult to be realistically employed at an operational scale (Putwain and Gillham 1990; Mackenzie and Naeth 2007; Macdonald et al. 2011).

The use of forest floor materials has shown potential to effectively reclaim understory plant communities (Grant et al. 1996; Rokich et al. 2000; Zhang et al. 2001; Mackenzie and Naeth 2009). The seed bank contained in the forest floor represents a significant source of seeds for development of plants in the future plant community (Greene et al. 1999). The use of forest surface material in reclamation therefore provides a source of propagules as well as nutrients for re-establishment of vegetation on reclamation sites (Mackenzie and Naeth 2009). However, due to operational limitations, these surface materials are often stored in stockpiles for a few months or even years. Stockpiling surface soil for as little as ten months has shown to significantly decrease the viability of the plant propagules (Iverson and Wali 1982; Koch et al. 1996; Rokich et al. 2000; Mackenzie and Naeth 2009) and results in poor plant establishment (Mackenzie and Naeth 2009).

Considering the limited success of using stockpiled material in establishing native species, it appears that shortening or eliminating the stockpiling of surface soil could be a viable reclamation technique that maintains higher viability of propagules. The direct transfer (also referred to as direct placement) of forest floor onto new reclamation sites is a relatively recent technique and has received little testing. Most tests have been conducted in mining sites in the Australian Jarrah forest (Grant et al. 1996; Rokich et al. 2000; Zhang et al. 2001).

In Alberta, surface mining operations are obliged to re-establish self-sustaining forest ecosystems and their functions after mining operations have ceased. In addition, mining operations are required to selectively salvage and reuse soil surface materials (Macdonald et al. 2011). In the boreal forest region of Alberta, there has been very limited testing of forest floor transfer as a capping material on an operational scale, but smaller studies have displayed promising results (Mackenzie and Naeth 2009). However, the direct placement of forest floor / surface soil material has not been employed due to the detailed planning that is required to carry it out (Mackenzie and Naeth 2007).

The overall objective of this study was to examine the effectiveness of direct forest floor transfer as a reclamation technique and to assess its ability to facilitate establishment of natural forest understory vegetation on mine reclamation sites. The goal was to effectively establish native understory plant species, and to speed up the process of forest succession by having fewer ruderal, and more later-successional understory species present on the reclamation site.

2.3 Methods

Research site description

The research was conducted at the Genesee Coal Mine, 80 km southwest of Edmonton, Alberta, Canada (lat 53°33'N, long 114°26'W). The coal mine is located in the dry mixedwood subregion of the boreal mixedwood forest natural region (Natural Regions Committee 2006). Undulating glacial till or lacustrine plains and hummocky uplands characterize this subregion. Forests dominated by aspen (*Populus tremuloides* Michx.) and scattered with white spruce (*Picea glauca* (Moench) Voss) are interspersed with fens throughout the subregion. Soils in upland areas are mainly Orthic Gray to Dark Gray Luvisols with medium to fine texture and are moderately well drained. Understory vegetation in this subregion is characterized by *Rosa acicularis* Lindl., *Corylus cornuta* Marsh., *Aralia nudicaulis* L., *Lathyrus ochroleucus* Hook., *Lathyrus nevadensis* S. Watson ssp. *lanceolatus* (Howell) C.L. Hitchc. var. *nuttallii* (S. Watson) C.L. Hitchc., and *Calamagrostis canadensis* (Michx.) P. Beauv. This subregion experiences the warmest summers and the mildest winters of all the subregions within the boreal forest (Natural Regions Committee 2006). The mean annual temperature is 3.1°C and the daily average temperature range is from -1.9 °C to 8 °C. The mean temperature in the summer is 14 °C (Environment Canada 2011). The long-term average annual precipitation is 540.2 mm, with an average of 408.7 mm of rain and 131.5 cm of snow (Environment Canada 2011). Climate information is based on a 30 years average (1961 to 1990) from the Stony Plain weather station (lat 53°32'N, long 114°6'W) (Environment Canada 2011).

The donor site was 4.6 ha in size, located within the Genesee coal mine lease area. The donor site consisted of an aspen-dominated forest stand that had been surrounded by farmland prior to Genesee acquiring the land. The donor site was an aspen stand that had been cut 11 years prior to this study and allowed to naturally regenerate via root suckering. The reclamation site was also located on the Genesee Mine lease, approximately 2.5 km from the donor site. The reclamation area was on a slightly sloped east-facing site in an area that had previously been mined, then re-filled with overburden material.

Donor site

Vascular plant composition and individual species abundances were measured in September 2009 using two parallel 250 m transects (60 m apart) along the full length of the donor site forest. Sample points were located at 25 m intervals along the transects. There was a small area in the donor forest where the vegetation had been bladed off three years prior to this vegetation survey. This area had a completely different vegetative composition, and therefore, although the area was sampled, data from the three sample plots that fell in this area were not included in the data analysis. Therefore, for the purposes of this study n = 17. At each sampling point a $1m^2$ quadrat was established for determination of species presence and abundance. To determine abundance, the number of individual plants (or the number of clumps for species with multiple stems) belonging to each species within the plot was assigned to one of three categories: category 1 for 1-5 stems, category 2 more 6-14 stems, and category 3 for > 15 stems. These categories were used because this vegetation survey was carried out in late September when it was difficult to estimate percent cover. For the purposes of this study, only vascular plant species were recorded.

To assess the seed bank species composition, samples of forest floor and surface mineral soil were taken with a soil corer (diameter = 15 cm) to a depth of 10 cm at each sample plot and halfway in between each sample plot to a depth of approximately 10 cm (n = 34). Soil cores were transported to the lab in plastic bags upright as one intact core, where they were stored in cold storage (-18°C) until the seed bank study commenced three months later (see below).

Seed bank

To identify the seed bank composition we followed the "seedling emergence method" outlined by Ter Heerdt et al. (1996). After three months of cold storage, the soil samples were prepared for the seed bank study. Each sample of the forest floor and surface soil was separated, using a knife, into the "upper layer" (the top 5 cm of the sample) and the "lower layer" (the lower 5 – 10 cm of the sample). All samples were separated at this depth to maintain consistency and because this was the point at which most samples transitioned from forest floor soil to mineral soil. Samples were then broken up by hand and put through a sieve shaker that separated particles based on size to remove large pieces of debris that did not contain seed and might impede seedling emergence. Particles between 4 mm and 0.5 mm were grouped together and used for the seed bank study. Subsamples of the particle sizes larger than 4 mm and smaller than 0.5 mm were collected and tested in the greenhouse to ensure that no seedlings were emerging from these portions of the samples. Plastic trays (20 × 45 cm × 5 cm) were filled to just under the halfway mark with a sterile soil mixture consisting of 5:1:1 peat:clay:perlite and 1.75 g of 13-13-13 (N-P-K) slow-release fertilizer with micronutrients (Acer, Delta, British Columbia). No-Damp (Plant Products Co. Ltd., Brampton, Ontario) was applied to the surface of the sterile soil to suppress the growth of fungi. This was done three days before the sieved soil samples were spread. The sieved samples were spread over top of the sterile soil in a layer no thicker than 2 cm (Mackenzie and Naeth 2007 & 2009; Abella et al., 2008). Trays were randomly arranged in the greenhouse, where conditions were kept to mimic ideal growing conditions at the field site. Samples were misted three times a day to maintain soil moisture, received 16 hours of light a day, and temperatures during the day were 21°C and 11°C at night (8 hours). For the first month, emerged seedlings were counted and removed from the trays weekly and planted in separate pots. If they could be identified, they were disposed of, and if they could not be identified, they were transplanted to pots to grow until identification was possible. The date of emergence of each plant was also recorded. After the first month, counts occurred once every two weeks. When germination slowed down, the surface soil was remixed to encourage additional germination of seeds and to break up the moss layer that had developed, in case it was impeding germination and to encourage buried seed to emerge (Ter Heerdt et al. 1996). The study continued for four months, until no new germinants were emerging.

Forest floor transfer

The reclamation technique being tested in this study was a "forest floor transfer" or direct placement of forest floor material. This entailed the removal of woody vegetation from the donor site (a site that is slated to be mined in the near future) by shearing off the trees at ground level with the blade of a D11 Caterpillar bulldozer during the winter when the ground was frozen. After removal of the trees, the forest floor and surface soil was stripped to a set depth and was immediately transported to the reclamation site, where it was spread at the same depth it had been stripped. Approximately 100 loads were transferred by Caterpillar 785C dump trucks carrying between 120 and 140 tonnes of material to the reclamation site during this process. At the research site, D11 and D10 Caterpillar bulldozers were used to spread the donor material directly on top of the overburden material that was covering the site. From the beginning of the material salvage to the completion of the material spreading, 16 days passed.

Reclamation site experimental design and sampling

The reclamation site was set up as blocked split-plot experiment with six experimental blocks (50 m width by 76 m length), each of which contained eight 25 m by 19 m subplots (total number of subplots = 48) (Figure 2-1). Within each subplot, four $1m^2$ permanent quadrats were systematically placed for sampling (total number of sampling quadrats = 192). These quadrats were surveyed for vegetative cover and abundance (based on the categories described above for the donor site) in mid-August 2010. Percent cover was estimated for each species to the nearest percent for percentages less than ten, and to the nearest five percent for percentages higher than ten. Species nomenclature followed USDA 2010.

Statistical analysis

The plant species identified in the vegetation survey were categorized into functional groups as follows. Firstly, by life-form: shrub, forb, or graminoid (as per USDA 2010). Secondly, species were categorized by original distribution: species that were native to Canada or species that were non-native to Canada (introduced) (as per USDA 2010). The third categorizing was by life history of the species: either perennial or annual/biennial (as per USDA 2010). Graminoid species that were unidentifiable because they did not flower were included as “unknown grass species" or "unknown sedge species". Species were considered "uncommon" if there were fewer than four individual plants in total found on the reclamation site, or if a species was present in less than 10% of the sample plots.

Statistical comparisons between the donor site and the reclamation site were not possible because there was no replication of the donor site. It would therefore not be possible to obtain statistically meaningful results because this donor site cannot represent a larger population of donor forest sites. Therefore, only descriptive statistics were used to compare the donor site with the reclamation site.

The aboveground and seed bank vegetation data were not normally distributed and could not be transformed, so the non-parametric Wilcoxon-Mann-Whitney Two-Sample Test was used to test for significant differences in response variables between the aboveground vegetation and the seed bank at the donor site. Response variables for the tests were species richness, the proportion of species in each sample that were either forbs, shrubs, or graminoids, the proportion of species in each sample that were native or non-native, and the proportion of species in each sample that was perennial or annual/biennial. These analyses were completed using proc npar1way in SAS 9.2 and α =0.05.

To test for significant differences in response variables between the upper and lower layers of the seed bank, the number of individual plants of each species emerging per tray was used rather than proportions. These data were not normal and could not be transformed, so a Signed-Rank non-parametric t-test was used. Response variables for these t-tests were the same as above, but referred to the number of individual plants of each species emerging per tray rather than proportions. These analyses were completed using proc univariate in SAS 9.2 and α =0.05.

A Nonmetric Multidimensional Scaling (NMDS) ordination was used to visualize variation in species composition between the aboveground vegetation at the donor site, the seed bank vegetation, and the reclamation site. NMDS was chosen because it can be used on non-normal data (McCune and Mefford 1997). Ordinations were performed on species abundance (number of individuals emerging) data transformed to represent a relative abundance (a percentage of the total number of plants in each quadrat or each sample for the seed bank) using PC-ORD version 4. The starting configurations were set to random and the stability criterion was 0.0005; the Sørenson (Bray-Curtis) distance measure was used. Initially, I did ten trial runs with real data, then using the results of Monte Carlo tests and the instability and stress values, the ideal dimensions for the ordinations were chosen. Three dimensions showed the best combination of low values for stress and instability, so 3D solutions were chosen for the final ordination. A final ordination was then performed using the output from the initial trial runs as the input for the final solutions. A Monte-Carlo simulation was used to test the significance of the ordination. The final solution had a total number of iterations of 130. Plots of stress vs. iteration were used to determine the final instability value of all ordinations, which was 0.005.

2.4 Results

Aboveground vegetation at donor site

The aboveground understory vegetation found at the donor site was typical of a young aspen forest stand in the dry mixedwood boreal forest subregion of Alberta (Natural Regions Committee 2006). The total understory species richness at the donor site, based on the 17 plots was 31 species (3 graminoids, 16 forbs, and 12 shrubs) (Table 2-1). All species were native and perennial. The most abundant and common species were *Cornus canadensis* L. (total of 149 individual plants found and present in 77% of plots), *Symphoricarpos albus* (L.) S.F. Blake (122 plants; 71% of plots), *Calamagrostis canadensis* (Michx.) P. Beauv. var. *canadensis* (105 plants; 65% of plots), *Lonicera involucrata* (Richardson) Banks ex Spreng. (101 plants; 77% of plots), and *Rosa acicularis* Lindl. (76 plants; 94% of plot).

Seed bank of donor site

The species composition of the seed bank was notably different from the aboveground vegetation of the donor site. The total species richness of the seed bank was 42 species (4 graminoids, 35 forbs, and 3 shrubs) (Table 2-1). Of these species, 29 were perennials and the remaining 13 were annuals or biennials. Thirty-two of the species were native and ten were non-native species. A total of 629 individual plants emerged in the seed bank study; which were contained in a total volume of 26,700 cm^3 of forest floor. The seed bank was dominated by one *Carex* species which could not be identified because it never flowered (168 plants, in 34% of samples), *Rubus idaeus* L. ssp. *melanolasius* (Dieck) Focke (59 plants, in 29% of samples), *Calamagrostis canadensis* (53 plants, in 32% of samples), *Taraxacum officinale* F.H. Wigg. (40 plants, in 43% of samples), *Veronica peregrina* L. ssp. *xalapensis* (Kunth) Pennell (39 plants, in 10% of samples), *Galeopsis tetrahit* L. (28 plants, in 24% of samples), and *Epilobium ciliatum* Raf. ssp*. ciliatum* (26 plants, in 29% of samples). The species that dominated the seedbank mostly fell into the ruderal or early successional category (e.g., *Carex* sp., *Rubus idaeus, Calamagrostis canadensis*, *Taraxacum officinale, Galeopsis tetrahit, Epilobium ciliatum, Corydalis aurea,* and *Veronica peregrina).* The first species to emerge in the seed bank study were *Galeopsis tetrahit, Taraxacum officinale, Rubus idaeus,* and *Corydalis aurea.* Other species that emerged within the first three weeks of the experiment included *Cirsium arvense* (L.) Scop., *Sonchus oleraceus* L., *Mertensia paniculata* (Aiton) G. Don. var. *paniculata, Melilotus officinalis* (L.) Lam., *Stellaria media* (L.) Vill., and *Cardamine pensylvanica* Muhl. ex Willd.

Soil depth significantly affected seed bank species richness, as richness per tray was higher in the upper organic layer (0 – 5 cm) than the lower more mineral soil layer (5 – 10 cm) (Table 2-2). However, the seed bank of the upper soil layer had a similar total emergence of 318 plants as the lower soil layer with 315. There was no significant difference in the numbers of plants emerging of native and non-native species, annual/biennial and perennial species, or shrub and graminoid species between the upper and lower soil layers (Table 2-2). The only plant functional groups that were significantly different between the upper and lower soil layers were the number of forb and non-native species. The upper soil layer had more forb and non-native species per tray than the lower layer. The forbs that were present only in the upper soil layer of the seed bank included *Cornus canadensis* L., *Erigeron elatus* (Hook.) Greene, *Mentha arvensis* L., *Solidago canadensis* L. var. *gilvocanescens* Rydb., *Stellaria media* (L.) Vill., *Thlaspi arvense* L., and *Viola nephrophylla* Greene. However, these species were uncommon and had fewer than two individuals. The lower soil layer also contained some species that were not present in the upper layer, including *Chenopodium album* L., *Chenopodium capitatum* (L.) Asch., *Cornus sericea* L. ssp. *sericea, Galium boreale* L., *Geranium bicknellii* Britton, *Ribes triste* Pall., *Vicia americana* Muhl. ex Willd.. These species were also uncommon and produced less than three individuals.

<u>Comparison of aboveground vegetation and belowground seed bank of donor site</u>

There was clear separation between the aboveground vegetation plots at the donor site and the seed bank samples in the NMDS ordination (Figure

2-2), which suggest that the species composition of the aboveground vegetation at the donor site was distinct from that of the seed bank (Table 2-3). There were 19 species in the aboveground donor site vegetation that were not present in the seed bank; all were native perennials; nine were shrubs, nine were forbs, and one was a graminoid species. Overall, nine of these species were uncommon.

There were 27 species present in the seed bank of the donor site that were not present in the aboveground vegetation. Twenty-two of these species were uncommon. The other five common species were *Epilobium ciliatum, Potentilla norvegica, Sonchus oleraceus, Taraxacum officinale, and Veronica peregrina.* Of the 27 total species, 25 were forbs and two were graminoids; eight were non-native; and 11 were annual or biennial. The number of forb species was not significantly different between the aboveground vegetation and the seed bank; however, the seed bank had more graminoid species than the aboveground vegetation, while the aboveground vegetation contained more shrub species. There were only three shrub species present in the seed bank (*Cornus sericea* L. ssp. *sericea, Ribes triste* Pall., and *Rubus idaeus* L. ssp. *melanolasius*) while the aboveground vegetation had 12 shrub species of which *Symphoricarpos albus*, *Lonicera involucrata*, and *Rosa acicularis* dominated.

The only species that dominated and were common in both the seed bank and the aboveground vegetation were the gramnoids *Carex* sp. and *Calamagrostis canadensis.*

<u>Reclamation site vegetation</u>

After the transfer of the forest floor material, the total species richness at the reclamation site after one growing season was 73 species (four graminoids, 59 forbs, and ten shrubs) (Table 2-1). Forty-nine species were native and 50 species were perennial. The most abundant species were *Galeopsis tetrahit* L. (based on the abundance categories we estimated 1314 individuals and the species was present in all 48 subplots), *Symphoricarpos albus* (approximately 703 plants found; present in all subplots), *Vicia americana* Muhl. ex Willd. (approximately 660 plants found, present in all subplots), *Calamagrostis canadensis* (approximately 460 plants found; present in 43 subplots), and *Rubus idaeus* ssp. *melanolasius* (approximately 446 plants found; present in 46 subplots). Four of the species that dominated the reclamation site can be considered ruderals or early successionals (*Calamagrostis canadensis, Galeopsis tetrahit, and Rubus idaeus,* and *Vicia americana*). Of the ten shrub species that were present, six of them were uncommon (present in less than 10% of the plots). The first species to emerge on the reclamation site were *Galeopsis tetrahit, Mertensia paniculata, Rubus idaeus, Calamagrostis canadensis,* and *Petasites frigidus* (L.) Fr. var. *palmatus* (Aiton) Cronquis.

Donor site (aboveground vegetation and seed bank) versus reclamation site vegetation

Of the 73 total species found at the reclamation site, 41 came from the donor site (the aboveground vegetation and the seed bank combined). The remaining 32 species were not present in the donor site vegetation but did emerge at the reclamation site (i.e., these species were "gained" at the reclamation site); this resulted in the reclamation site having a higher richness than the donor site (Table 2-4 and 2-5). Of those 32 gained species, 18 were native and 21 were perennial. While the number of native species at the donor site was similar to the reclamation site, only 28 of the 49 native species found on the reclamation site were also found at the donor site. Twenty-one native species that were present at the donor site (including the aboveground and the seed bank vegetation) were not present at the reclamation site (these species were "lost" in the soil transfer) (Table 2-5). All of these species were native, and 19 were perennial.

The NMDS indicated that there were few similarities between the vegetation composition of the aboveground vegetation at the donor site and the vegetation establishing on the reclamation site (Figure 2-2). Of the species that had been present at the donor site but were not found at the reclamation site, 12 were forbs and five were shrubs. Interestingly, *Cornus canadensis*, which was the most abundant aboveground species at the donor site, was not found on the reclamation site. Other plants from the donor site that were not found in the reclamation site included *Mitella nuda* L., *Cornus sericea* L. ssp. *sericea, Corylus cornuta* Marsh., *Erigeron elatus* (Hook.) Greene, *Lonicera dioica* L., *Pyrola asarifolia* Michx., *Solidago canadensis* L. var. *gilvocanescens* Rydb., *Viburnum edule* (Michx.) Raf., *Viburnum opulus* L. var. *americanum* Aiton, *Viola canadensis* L. var. *rugulosa* (Greene) C.L. Hitchc., *Viola nephrophylla* Greene.

The NMDS ordination did; however, indicate that there was an influence of the donor site seed bank on developing vegetation at the reclamation site (Figure 2-2). The grass *Calamagrostis canadensis,* along with *Rubus idaeus* and *Galeopsis tetrahit* were dominant species in the seed bank of the donor site and at the reclamation. Of the species that were found in both the donor site seed bank and the reclamation site, the only species that was dominant at the reclamation site but not in the donor site seed bank was *Vicia americana.*

2.5 Discussion

<u>Impact of forest floor transfer on maintaining forest understory composition</u>

The results of the study show that the direct forest floor transfer method has the potential to augment the number of native species that establish on reclamation sites in the first year. After the first growing season, the reclamation site contained 20 species that were present in the aboveground portion of the donor site. As a result, this method allowed the transfer of 65% of the aboveground species to the new reclamation site. In total, 73 species were found at the reclamation site, which indicates that new species were added either through the seed bank of the donor site or from areas outside of the reclamation site. This result suggests that this method was more effective at transferring plant propagules than using stockpiled material, which is similar to results of a growth chamber seed bank experiment in North Dakota which found only 35% of total species (9 out of a possible 26 species in unstockpiled soil) germinated in stockpiled soil (Iverson and Wali 1982). The result of our study also indicates that the direct forest floor transfer method may speed up the recovery process, similarly to a study in Russia that looked at natural recovery after mining found that it took between 12 to 20 years for a pioneer community consisting of mostly of grasses, sedges, horsetails, and green mosses to develop (Pugachev et al. 2004). The community composition of the reclamation area in our study is already that of a pioneer community in the first year, and it is likely that it will have continued to develop to a later successional community in twelve years time.

Although the donor site was a young forest, the aboveground vegetation assemblage had a composition that would not be considered early successional as the species that dominated the understory were typical of a mature aspen forest (Macdonald and Fenniak 2007). The species that dominated the seed bank were characteristic of a more ruderal, early successional plant community than was represented in the aboveground vegetation. The two components of the donor site, the aboveground vegetation and the seed bank, together provide a wide variety of species that represent the potential for plant regeneration at the reclamation site (Greene et al. 1999).

After the first growing season, the vegetation of the reclamation site still clearly represented a recently disturbed / very early successional stage and the original donor site species composition was not fully represented. This was not unexpected in the first year, however, because the site was open and had just experienced a large soil disturbance and would therefore be expected to be mainly dominated by mostly early successional or ruderal species (Grime 1977). Overall, 14 new non-native species were gained at the reclamation site; however, 65% of species of the original donor site were still represented on the reclamation site. The proportions of native to non-native and perennial to annual / biennial species we observed were similar to results of a soil transfer study conducted on a reclamation site in the central mixedwood region of Alberta (Mackenzie and Naeth 2009). They concluded that the direct placement method had the potential to develop into communities that were similar to undisturbed upland forests due to the presence of many propagules in the reclamation material. In our results, the dominance of the early successional species and the arrival of additional species at the reclamation site clearly indicated that the community on the reclamation site was very different from the aboveground vegetation of the donor site. Whether the plant community on the reclaimed site will eventually become similar to the donor site understory community likely depends on the development of a forest canopy on the reclaimed site.

The development of an overstory canopy layer may be beneficial in re-establishing a more natural understory forest plant community at the reclamation site. This can be achieved by planting trees or using the ability of aspen to vegetatively regenerate from roots contained in the transferred soil (Wachowski et al. unpublished). A developing canopy would reduce light reaching the forest floor and eventually cause the forest floor to become darker, moister, and cooler (Hart and Chen 2006). As these changes occur, the ruderal / shade intolerant species will begin to die out and cease to germinate (Grime 1977). This will allow the later successional species to dominate and for more to establish, possibly at a higher density (McCook 1994). As this process continues, the presence of the native forest species that were transferred from the donor site may help accelerate succession to a more natural forest vegetation.

Importance of bud bank and neighbouring sites

On a newly reclaimed site, there are two important sources for revegetation: 1) seed and vegetative propagules contained in a seed or bud bank (Zasada et al. 1992); and 2) off-site seed dispersal (Qi and Scarratt 1998). The species that were gained during or after the transfer likely arrived on the site through long distance dispersal (wind or animals) from the surrounding area, or on the machinery transferring the soil (Olmstead and Curtis 1947; Bakker et al. 1996; Johansson et al. 1996). However, there is also a possibility that some species that were 'gained' on the reclamation site were present in the aboveground vegetation at the donor site but were not detected in our sampling. In a study using soil that had been stockpiled for either one week or one year, Iverson and Wali (1982) concluded that initial recovery after reclamation is dependent on colonization from seeds from neighbouring areas, and later on (more than two years), revegetation is more dependent on the seed bank. Therefore, the species composition on our reclaimed sites may change in future years as site conditions change and additional seeds still contained in the seed bank might germinate and establish.

Two of the five dominant species at the reclamation site were shrubs (*Symphoricarpos albus* and *Rubus idaeus*), and it was observed that plants of these two species grew to be much larger than most of the other plants at the reclamation site. Both of these shrub species are capable of reproducing vegetatively from buds (Pratt et al 1984; Whitney 1986). The rapid dominance of these species on the reclamation site suggests they had a propagule source that was present ubiquitously throughout the reclamation site and was able to grow rapidly in the first season of growth. Although we did not determine whether individual plants grew from buds or seeds, these results suggest that these shrubs regenerated vegetatively from buds that were successfully transferred from the bud bank to the reclamation site. This finding supports the idea that the bud bank, along with the seed bank, plays an important role in species regeneration for this reclamation technique.

Timing of establishment

There were some similarities in the species that first emerged in the seed bank study in the greenhouse and at the reclamation site. *Galeopsis tetrahit*, *Mertensia paniculata*, and *Rubus idaeus* were among the first species to emerge in both cases. This is interesting since these species have different characteristics. Whereas *Galeopsis tetrahit* and *Rubus idaeus* are ruderal species (Hughes and Fahey 1991) and would thus be expected to emerge quickly under conditions of full sunlight and no competition, it is somewhat surprising that *Mertensia paniculata*, which is a perennial forb and not considered a ruderal, emerged so quickly in both instances. A possible explanation is that, like the shrubs discussed above, the *Mertensia paniculata* buds survived the soil transfer exceptionally well; thus new plants were able to establish quickly from the buds at the reclamation site.

It is interesting that the two ruderal species, *Galeopsis tetrahit* and *Rubus idaeus* were dominant species in both the seed bank and at the reclamation site, but *Mertensia paniculata*, despite emerging as one of the first species, was not dominant at either site. This shows that although *Mertensia paniculata* did demonstrate the ruderal quality of rapid emergence; however, it was not able to keep up with the other two species in terms of the classic traits of ruderal species (Grime 1977) to rapidly spread across the site or emerge in great numbers.

<u>Autecology of species gained and lost in soil transfer</u>

There were 21 species that were lost from the donor site plant community after the transfer while 32 new species were gained at the reclamation site. The autecology of the lost and gained species in relation to the disturbance and the differences in resource availability between the donor and reclamation sites may help explain the patterns of these gains and losses.

The difference in the availability of light at the two sites may have been important since it is well documented that ruderal, early successional species grow more successfully in high light conditions (Hart and Chen 2006; Gunton et al. 2010). The lack of a tree canopy on the reclamation site resulted in much higher light availability than at the donor site. This likely facilitated the rapid establishment and growth of ruderal / shade intolerant species at the reclamation site (Gould and Gorchov 2000; Miller and Gorchov 2004).

Two native understory obligates and highly shade tolerant forbs, *Pyrola asarifolia* and *Mitella nuda* (Humbert et al. 2007; Macdonald and Fenniak 2007; Strong and Redburn 2009) did not make the transfer to the reclamation site. *Pyrola asarifolia* is restricted to forested areas, and is very specific to aspen and sometimes birch stands (Eulert and Hernandez 1980), while *M. nuda* is more associated with the understory of conifer forests

(Macdonald and Fenniak 2007). Neither *P. asarifolia* nor *M. nuda* emerged from the seed bank study, suggesting that if they were present in the seed bank, their requirements to break their seed dormancy were not met in our study. It is possible that these requirements were not met at the reclamation site either; therefore, if the seeds of these species successfully survived the soil transfer, they might still be dormant in the seed bank of the reclamation site, waiting for favourable conditions – for example, when there is more shade at the site and therefore less competition for resources from shade-intolerant species. The dissimilarity between aboveground and seed bank vegetation could be due to the ability of seeds of some species to remain dormant in the seed bank for very long periods of time (Finch-Savage and Leubner-Metzger 2006). For example, Marquis (1975) suggests that the seeds of the early successional shrub *Prunus pensylvanica* can remain dormant in the seed bank for over 30 years.

Three shrub species that were present at the donor site, *Cornus sericea, Corylus cornuta*, and *Viburnum edule* were also lost in the transfer to the reclamation site. The dwarf shrub, *Cornus canadensis,* which was the most abundant aboveground species at the donor site, was also not found at the reclamation site. The habitat that these species are most often found in is the understory of upland forests and thickets (Eulert and Hernandez 1980; Haeussler et al. 1990), where they have some shade and there is likely greater soil moisture than the reclamation site currently has. The seeds of these species have the ability to remain dormant in the soil for many years until conditions are favourable for their growth (Haeussler et al. 1990). Therefore, it is possible that conditions at the reclamation site are not yet favourable for these species and the seeds are still dormant in the soil (Fyles 1989). *Cornus canadensis* is an evergreen species, which does not require as much direct light as some other herb species for successful growth (Landhäusser et. al 1997). This species reproduces by seeds and also through vegetative reproduction by means of underground rhizomes (Hall and Sibley 1976). Seed reproduction is a much less important means of reproduction than vegetative reproduction for these three shrub species, and this may also be the case for *C. canadensis* in this situation (Eulert and Hernandez 1980; Haeussler et al. 1990). Thus, their absence at the reclamation site could be due to a lack of success in transfer of vegetative propagules to the reclamation site, or damage of them during the transfer process.

Of the ten shrubs species that were found on the reclamation site, six were uncommon. Therefore, although these shrubs were present, they did not make up a large part of the vegetation at the reclamation site in the first season of growth. It is possible that in the following growing seasons, these shrub species may begin to spread and become a larger part of the vegetation. As many of the shrubs present at the reclamation site are considered semi-shade tolerant to shade-tolerant (Hauessler et al. 1990; Humbert et al. 2007; Macdonald and Fenniak 2007), it is possible that establishment of tree canopy cover could further facilitate establishment of these species. This would be a desirable result as shrubs represent a later stage of succession in the forest understory and the goal of the reclamation technique is to speed up the process of succession (Burbanck and Phillips 1983). As it will likely take several years for a tree canopy to develop providing adequate shade for optimal shrub growth, the development of a shrub layer is likely a longer-term goal for this reclamation technique.

Caveats

It is important to note that the data from the reclamation site vegetation surveys represents only the first season of growth after the forest floor transfer took place. It is possible and likely that some of the seeds in the soil did not germinate within this first growing season. The seeds of many of the species found in the seed bank study have the ability to remain dormant in the seed bank for many years until conditions are favourable to break dormancy. For example, the seeds of *Rubus idaeus* are estimated to remain dormant and viable in the seed bank for up to 50 to 100 years (Graber and Thompson 1978; Whitney 1986). Therefore, it is highly likely that additional species will emerge from the seed bank on the reclamation site in later years. As discussed above, as the conditions at the reclamation site change over time, it is likely that different species with different site requirements will begin emerging from the seed bank and that the relative abundances of species will change. For example, in a similar direct placement study in the Alberta oil sands region, Mackenzie and Naeth (2009) found that during the second year of growth, the plant density increased by 22 times at the reclamation site.

2.6 Conclusions

In order to reclaim disturbed surface mined areas in the boreal forest to functioning forest ecosystems, the inclusion of an understory community is vital. It used to be a common practice during mining operations to keep surface soils in stockpiles for up to decades, a practice that results in substantial reductions in the number of viable propagules available for revegetation when that material is finally used as a cover soil. The direct placement of forest floor can speed up the process of succession by providing viable native propagules (seeds and buds) for revegetation at reclamation sites. Although our results show that this method still initiates an early successional vegetation community at the reclamation site, it does facilitate the establishment of native forest understory species on the reclaimed site. From a reclamation point of view, this method is very promising as it introduced many native understory species to the reclamation site and could move the recovering forest system more quickly to a diverse understory plant community. This sets the reclamation site plant community on a path whereby it has the potential to eventually resemble more closely the vegetation community of the donor site as later successional understory species are initiated on the site.

This technique has the potential to be implemented operationally, but requires good planning of mine operations in order to be effective, as the movement of the forest floor materials needs to be coordinated with the reclamation activities in the mined areas. Operationally this technique could also reduce costs as the material is only transported once to the final destination compared to stockpiling where it would be moved twice.

2.7 Literature cited

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Tables

Table 2-1. Total number of species by plant functional group encountered in sampling for each component of the donor site (aboveground and seed bank vegetation) as well as the two combined and for the reclamation site. The aboveground donor site was sampled in September 2009, the seed bank was sampled between January and May 2010 in a greenhouse, and the reclamation site was sampled in mid-August 2010.

	Donor Site			Reclamation Site
Plant Group	Above-ground	Seed Bank	Combined Total	Total
Total	31	42	62	73
Graminoids	3	4	5	4
Forbs	16	35	45	59
Shrubs	12	3	12	10
Annuals / Biennials	0	13	13	23
Perennials	31	30	49	50
Natives	31	32	52	49
Non-natives	0	10	10	24

Table 2-2. Median number of plants (and confidence interval) emerging per tray from the seed bank greenhouse experiment. Also given is the total number of species in each functional group emerging from the samples of the upper and lower seed bank layers. Results (P-values) are given for the comparison of the number of individual plants of each species emerging per tray between the upper and lower soil layers. These data were not normal and could not be transformed, so a Signed-Rank non-parametric t-test was used. P-values in bold are significant at α = 0.05.

	Upper Layer			Lower Layer			P-Value
Plant Group	# of Species	Median	5^{th} – 95^{th} percentile	# of Species	Median	5^{th} – 95^{th} percentile	
Total	35	5.0	2.0 – 7.0	31	3.0	1 – 7.4	**0.0073**
Graminoids	4	1.0	0 – 11.4	2	1.0	0 – 21.8	0.6270
Forbs	29	4.5	1 – 14.2	26	3.0	0 – 14.4	**0.0138**
Shrubs	2	0	0 – 3.4	3	0	0 – 5	0.4713
Annuals / Biennials	10	1.0	0 – 7.5	10	1.0	0 – 9.4	0.9911
Perennials	25	6.0	2 – 16.8	21	3.0	0 – 29.7	0.1263
Natives	26	4.0	1 – 21.1	23	4.0	0 – 31.8	0.5750
Non-natives	9	2.0	0 – 6.4	8	1.0	0 – 3	**0.0007**

Table 2-3. Comparison of aboveground vegetation and seed bank vegetation at the donor site based on proportions of species in each functional group. P-values represent results of Wilcoxon-Mann-Whitney Two-Sample Tests. Number of total species in each functional group is also shown. P-values in bold are significant at $\alpha = 0.05$.

	Aboveground Vegetation			Seed Bank Vegetation			
Plant Group	# of Species	Median proportion of total species	5th – 95th percentile	# of Species	Proportion of total species	5th – 95th percentile	P-Value
Total	31	–	–	42	–	–	–
Graminoids	3	0.1	0 – 0.3	4	0.3	0 – 0.8	**0.0313**
Forbs	16	0.5	0.1 – 0.7	35	0.6	0.1 – 1.0	0.0772
Shrubs	12	0.4	0.2 – 0.6	3	0.1	0 – 0.5	**<0.0001**
Annuals / Biennials	0	0	0 – 0	13	0.2	0 – 0.5	**<0.0001**
Perennials	31	1.0	1.0 – 1.0	30	0.8	0.5 – 1.0	**<0.0001**
Natives	31	1.0	1.0 – 1.0	32	0.7	0.4 – 1.0	**<0.0001**
Non-Natives	0	0	0 - 0	10	0.3	0 – 0.6	**<0.0001**

Table 2-4. Comparison of donor site (including aboveground and seed bank) vegetation and reclamation site vegetation based on proportions of species in each functional group. Statistical comparisons between the donor site and the reclamation site were not possible because there was only one replicate of the donor site.

	Donor Site Vegetation		Reclamation Site Vegetation	
Plant Group	# of Species	Proportion of total species	# of Species	Proportion of total species
Total	62	1.0	73	1.0
Graminoids	5	0.1	4	0.1
Forbs	45	0.7	59	0.8
Shrubs	12	0.2	10	0.1
Annuals / Biennials	13	0.2	23	0.3
Perennials	49	0.8	50	0.7
Natives	52	0.8	49	0.7
Non-Natives	10	0.2	24	0.3

Table 2-5. Species "lost" and "gained" in the forest floor transfer. Species gained were species that were not present in the donor site vegetation, (including aboveground and the seed bank) but did emerge at the reclamation site (out of a total of 73 species at the reclamation site). Species lost were present at the donor site (out of a total of 62 donor site species), but were not present at the reclamation site.[1]

	Total # Species Lost at Reclamation Site	Total # Species Gained at Reclamation Site
Total	21	32
Graminoids	4	2
Forbs	12	26
Shrubs	5	4
Annuals/Biennials	2	11
Perennials	19	21
Natives	21	18
Non-Natives	0	14
Common	9	7
Uncommon	12	25

[1]Species were considered "uncommon" if there were fewer than four individual plants in total found on the reclamation site, or if a species was present in less than 10% of the sample plots.

Figures

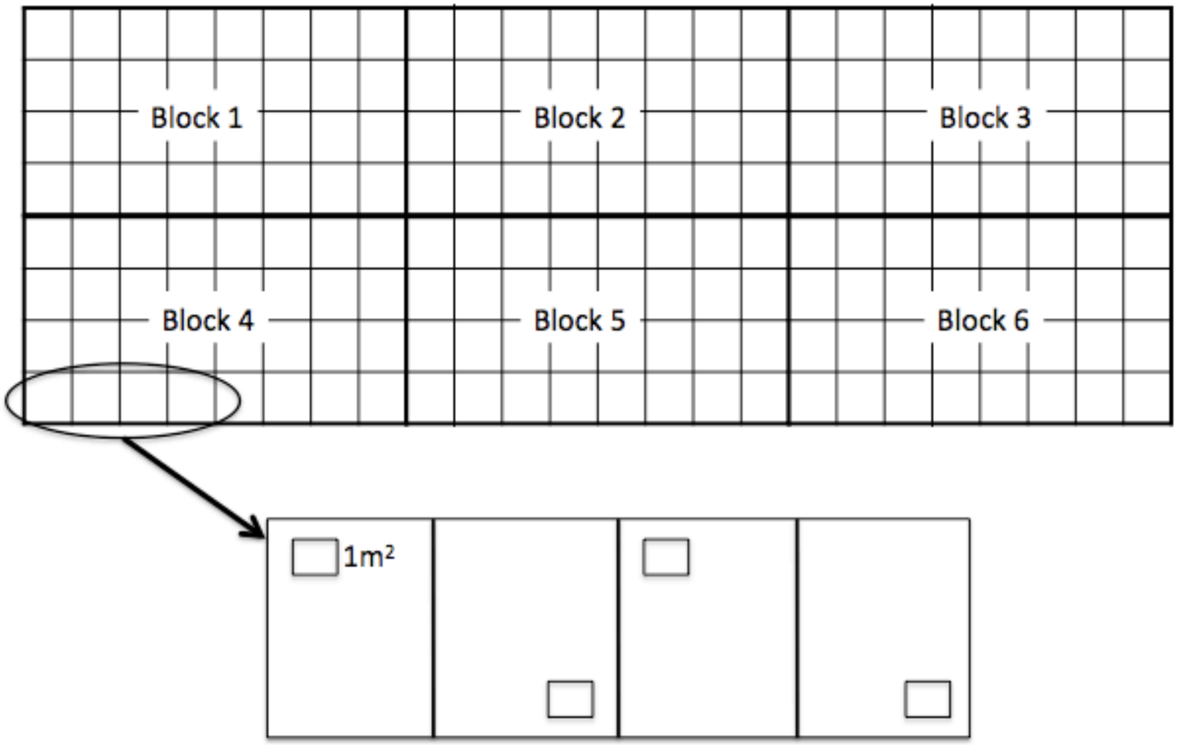

Figure 2-1. Reclamation site set-up consisted of six experimental blocks each of which contained eight subplots (total number of subplots = 48). Within each subplot, four 1 m^2 permanent quadrats were systematically placed for sampling (total number of sampling quadrats = 192). The quadrats were surveyed for species vegetative cover and abundance (based on the categories described for the donor site – see Methods) in mid-August 2010.

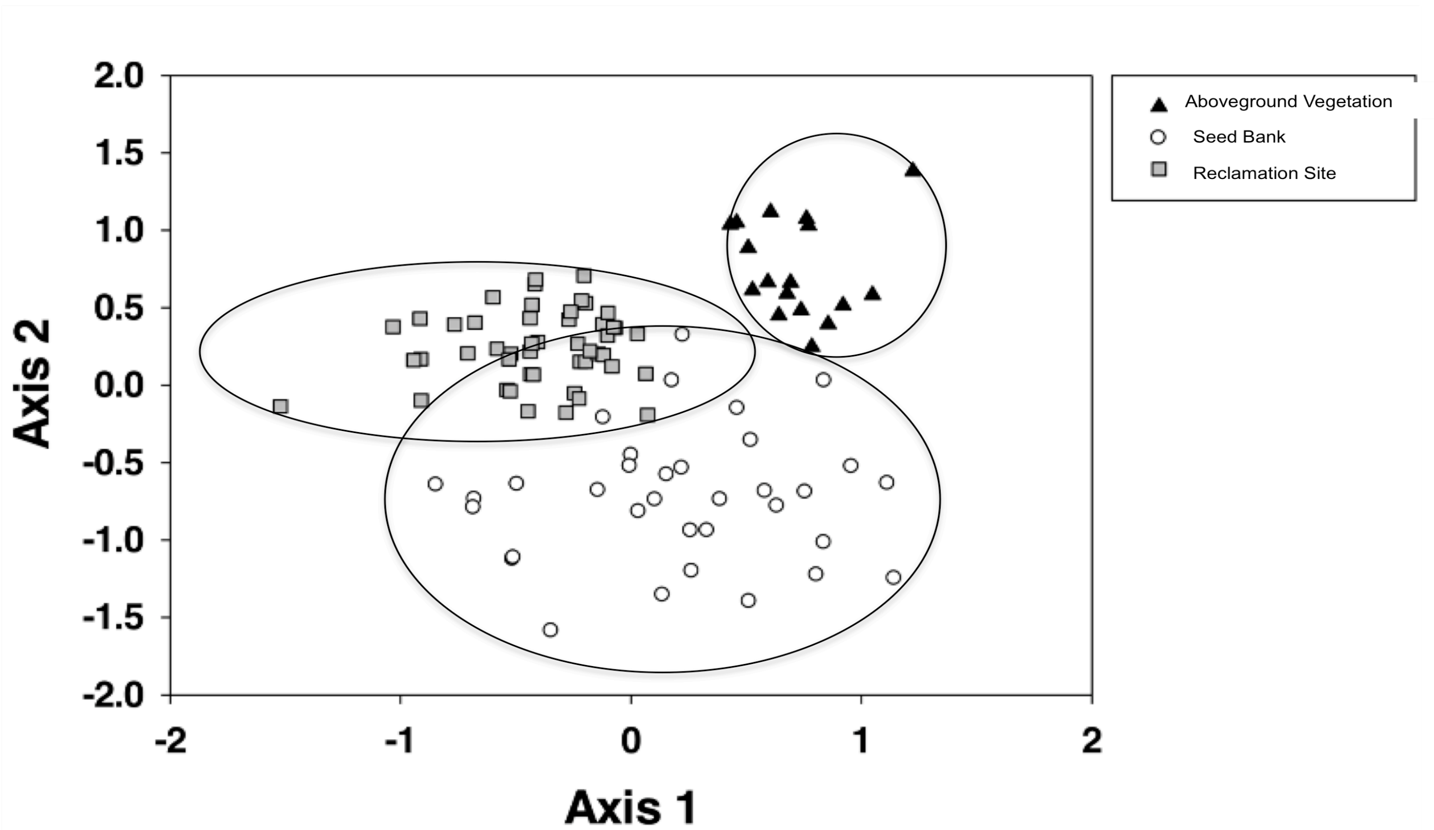

Figure 2-2. Results of NMDS Ordination of the aboveground donor site plots, seed bank samples, and reclamation site plots. The ordination shows no overlap of plots between the aboveground vegetation at the donor site and the reclamation site, but there is some overlap between plots in the seed bank and at the reclamation site.

Chapter 3: Effect of salvage depth and direct placement of forest floor on the initiation of forest understory plant communities on boreal reclamation sites

3.1 Summary

At a coal mine in Alberta, Canada, a “forest floor transfer” reclamation project took place in which forest floor material was salvaged at two depths (15 and 40 cm) from a native aspen forest and immediately placed at the same depths on a reclamation site. The objective of this study was to determine how depth of salvage and placement influences the initial plant community on the reclamation site. Vegetation surveys were conducted at the reclamation site during the first growing season after reclamation. Species cover and abundance were higher in the 15 cm treatment than in the 40 cm treatment. Sixty-nine species were found at the 15cm depth and only 58 at the 40 cm depth. The species that were missing at the 40 cm treatment were a mixture of annual, non-native species and perennial, native species. However, all the species that were not found at the 40 cm depth were uncommon at the 15 cm treatment. The species compositions for both depth treatments were very similar to each other and both were distinct from that at the donor site. The results of this study indicate that either depth treatment could be used to facilitate more rapid establishment of a diversity of native boreal understory forest plants on a reclaimed landscape.

3.2 Introduction

Forested lands around the world are being disturbed at an increasing pace to keep up with the increasing demand for mined resources. While forest reclamation has generally focused on the re-establishment of trees, the understory is a vital component of a functional forest, and reclamation efforts must focus on this component as well. Traditional reclamation practices of surface mined lands include stockpiling the mined surface- and subsoil together, then re-spreading it over the site once mining activities cease. However, this practice tends to result in low species establishment from the material that was placed on the reclamation site (Koch et al. 1996). Therefore, in recent years, researchers have focused on approaches that increase the establishment of forest understory plant species on reclamation sites. To achieve this, research has focused on testing selectively salvaging different layers of the soil, which also have different propagule counts. In the oil sands mining region of Alberta, Mackenzie and Naeth (2009) tested an approach that involved the salvage of the forest floor (also referred to as the LFH layer) as a material to establish native plants on reclamation sites with promising results. In addition, studies on selectively salvaged soil have shown that storing soil surface materials in stockpiles for even as little as ten months (Koch et al. 1996) significantly decreases the viability of the propagules within that material (Iverson and Wali 1982; Rokich et al. 2000;

Mackenzie and Naeth 2009). Therefore, a technique that selectively salvages soil layers and transfers them directly to the reclamation site eliminates the use of stockpiles, preserves natural propagules and has the potential to be more effective in establishing native understory plants at a reclamation site.

The forest floor transfer reclamation method (also referred to as "direct placement" in other papers) is one which both selectively salvages forest floor material and eliminates the use of stockpiles by directly transferring forest floor material to the reclamation area after salvage. The purpose of this reclamation practice is to facilitate native plant species establishment on reclamation sites. It is known that the number of plant propagules decreases with increasing soil depth as the propagule-rich top layer of forest floor is receiving most of the seed rain by the species (Harper 1977; Tacey and Glossop 1980; Putwain and Gillham 1990; Rokich et al. 2000). Thus, it is unclear what the impact will be of including salvage of the deeper, propagule-poor forest floor or surface mineral soil layers and mixing these with the propagule-rich surface forest floor material during placement.

Of the limited studies that have tested the direct placement of forest floor / topsoil without stockpiling it, a few have endeavored to address the question of the salvage and placement depth. Salvaging too deeply could dilute the seed bank and decrease seedling emergence (Tacey and Glossop 1980; Putwain and Gillham 1990; Grant et al. 1996; Rokich et al. 2000; Mackenzie and Naeth 2009) while salvaging too shallow can be operationally impossible (Tacey and Glossop 1980; Koch et al. 1996; Rokich et al. 2000) or could result in wasting part of the potential propagule pool. Studies carried out in the Australian Jarrah forest recommend applying forest floor materials at a shallower depth (e.g. 10 cm) to achieve higher plant density, species richness, abundance, and seedling emergence (Rokich et al. 2001; Holmes 2001). Conversely, in a direct placement experiment in the oil sands region of the Alberta boreal forest, Mackenzie and Naeth (2009) found that 18 months after application, the 20 cm depth treatment had significantly higher richness than the 10 cm depth treatment. However, the question of the impact of deeper salvage and placement depths of directly placed cover soil remains unanswered.

The effect of seeding different species of cover crops on the development of the understory plant community at the reclamation site was also examined in this study. Cover crops are often used in reclamation projects to provide a vegetation cover quickly and to aid in controlling erosion (OSVRC 1998; Rowland et al. 2009). In Alberta, barley (*Hordeum vulgare* L.), a non-native grass, is a commonly used cover crop. In our study, we wanted to test the potential of using other species, such as natives or forbs, as cover crops to effectively provide a vegetation cover to compare with the effect of barley.

The objective of this study was to determine how forest floor salvage and placement depth affects the establishment of a forest understory plant community at a reclamation site and what role cover crops and other ruderal plant species could play in the initial development of the understory community.

3.3 Methods

Research site description

This research project was undertaken at a reclamation site located at the Genesee Coal Mine, 80 km southwest of Edmonton, Alberta (lat 53°33'N, long 114°26'W). The mine is located in the dry mixedwood subregion of the boreal mixedwood natural region of Alberta (Natural Regions Committee 2006). This region is made up of undulating glacial till or lacustrine plains and hummocky uplands. Forests in the region are dominated by aspen and scattered with white spruce. Upland area soils are mainly Orthic Gray to Dark Gray Luvisols with medium to fine texture and are moderately well-drained. Dominant understory vegetation in the dry mixedwood subregion includes *Rosa acicularis* Lindl., *Corylus cornuta* Marsh., *Aralia nudicaulis* L., *Lathyrus ochroleucus* Hook., *Lathyrus nevadensis* S. Watson ssp. *lanceolatus* (Howell) C.L. Hitchc. var. *nuttallii* (S. Watson) C.L. Hitchc., and *Calamagrostis canadensis* (Michx.) P. Beauv. The climate in this subregion is the warmest of all the subregions within the boreal forest, experiencing the warmest summers and the mildest winters (Natural Regions Committee 2006). The daily average temperature in the summer is 14°C and average temperatures are below -10°C for the four coldest winter months (Natural Regions Committee 2006; Environment Canada 2011). The average annual precipitation is 540.2 mm, of which 408.7 mm falls as rain and 131.5 cm as snow (Environment Canada 2011). This climate information is based on data from the Edmonton Stony Plain weather station (lat 53°32'N, long 114°6'W) between the years 1961 and 1990 (Environment Canada 2011).

The donor site was a 4.6 ha area that was slated to be mined in the near future, located within the Genesee coal mine lease. The site was an aspen-dominated forest that, prior to Genesee acquiring the land, had been surrounded by farmland. The donor site was an original aspen (*Populus tremuloides* Michx.) stand that had likely never been farmed. The stand was cut 11 years prior to the start of this study and allowed to naturally regenerate via root suckering. The reclamation site was located approximately 2.5 km away from the donor site, also on the Genesee Mine lease. This site was located on an east-facing hill with a slight slope ranging from 5 to 12 degrees. The reclamation site was a site that had been mined for coal in the past then re-filled with overburden material.

<u>Forest floor transfer</u>

For this experiment, two different salvage depths, 15 cm and 40 cm, were tested. These depths were chosen for several reasons. Firstly, these depths were chosen specifically for the conditions at the donor site. The 15 cm depth was chosen because this depth included most of the forest floor material and most of the root systems and propagules of the site (see chapter 2). Since effective tree rooting depth was to a depth of approximately 40 cm, it was possible to salvage to depth of 40 cm without hitting bedrock or unsuitable or confining rooting substrates such as heavy clay. Therefore, at the 40 cm salvage depth the forest floor as well as the mineral soil horizons were still of good quality (did not include any Bt or C horizon material). These depths were also chosen because they fell within the range of previously tested depths for similar reclamation projects that have shown some potential to be effective at establishing native understory plants at reclamation sites (Tacey and Glossop 1980; Rokich et al. 2000; Mackenzie and Naeth 2009). Finally, they were chosen because another goal of this experiment was to test the effectiveness of transferring the roots of the aspen trees to the reclamation site for their propagation on that site. It was hypothesized that the aspen root transfer may be more effective with the 40 cm salvage depth because there would be more mineral soil present to aid in capturing and holding water, keeping the roots segments hydrated and alive longer. This was being compared to the 15 cm depth which would consist of less mineral soil (Wachowski et al., unpublished data).

The forest floor transfer occurred in February of 2010, when temperatures in the region were well below freezing and the ground was frozen to more than 30 cm depth. To prepare the donor site area, trees were sheared off at ground level using the straight blade of a D11 Caterpillar bulldozer and removed. The forest floor and surface soil material was pushed into windrows, maintaining separate windrows for the two salvage depth treatments of 15 cm and 40 cm. During the salvage operations the material that was salvaged for the 40 cm treatment was generally handled more than the 15 cm treatment, as the bulldozer had to make several passes back and forth over the salvage area in order to achieve a salvage depth of 40 cm. Although operators set out to salvage to exactly 15 and 40 cm, there were some problems with accuracy of salvage, and in some cases, material was salvaged up to 20 cm deeper than the target depth. However, the depth treatments always kept their relative difference to each other, as the “15 cm” salvage was always shallower than the “40 cm” salvage. Once the salvage was complete to the appropriate depths (six days from start to finish), the forest floor material was loaded into Caterpillar 785C dump trucks carrying between 120 and 140 tonnes with a Cat Large Wheel Loader. The two treatment levels were loaded separately and the material was transported to the reclamation site. Approximately 100 loads were transferred to the reclamation site. At the reclamation site, treatment blocks were delineated to indicate which areas should receive the 15 cm and 40 cm salvage and placement treatments. The material was spread over the site with D11 and D10 Caterpillar bulldozers in the appropriate treatment blocks, directly over top of the overburden material that was covering the reclamation site. During the placement process, the 15 and 40 cm depths were adhered to more closely (within 5 cm of the target depth) than they had been during the salvage process although material was placed slightly deeper at the bottom of the slope than at the top. At this stage, the 40 cm material was again handled more than the 15 cm material as there was more of it to load, transport, and spread. In total, it took 16 days to complete the salvage and transfer of approximately 4.6 ha of forest.

Experimental design

The reclamation site was set up to test the effects of two factors on the early post-disturbance development of the plant community: salvage depth (15 cm and 40 cm) and cover crop seeding. Four different cover crop treatments were tested: the annual non-native grass barley (*Hordeum vulgare* L.), the perennial native fireweed (*Chamerion angustifolium* (L.) Holub ssp. *angustifolium*), the biannual non-native sweet clover (*Melilotus officinalis* (L.) Lam.), and no cover crop, to act as a control. Barley was chosen as a cover crop for its ability to grow quickly and provide vegetation cover and control erosion (OSVRC 1998; Rowland et al. 2009), and sweet clover and fireweed were chosen because it was expected that these species could quickly establish a canopy cover suppressing the growth and establishment of more competitive species that could dominate the plant community (Landhäusser et al. 1996). The reclamation site was set-up to house 6 experimental blocks, which were, on average, 50 m in width and 76 m in length. Half of each experimental block was randomly assigned to one of the depth treatments. The cover crop treatments were split-plots within the depth treatments. Thus, each area receiving a given depth treatment was divided into four plots that were randomly assigned to one of the four cover crop treatments (Figure 3-1). Each of these four plots was further subdivided into four equal-sized subplots; in each of these, one permanent quadrat (1 m^2) was set up for vegetation and nutrient sampling (n = 192). Blocks, treatment plots, and vegetation plots were set up at the reclamation site in mid-May 2010. Seeds of each cover crop were tested in laboratory conditions and found to have extremely high germination rates. The cover crops were seeded with an Earthway Ev-n-spread seeder on the 20th of May 2010. Barley was seeded at a rate of 9.1 kg/ha, sweet clover at 0.2 kg/ha, and fireweed at 2.7 kg/ha. These seeding rates were chosen based on typical seeding rates for reclamation projects in the Athabasca Oil Sands region.

Soil nutrient sampling

Plant root simulator (PRS) probes (Western Ag Innovations Inc., Saskatoon, Canada) were used to sample the soil for bioavailable nutrients. The probes are used in pairs, one which measures cations and the other anions. The probes consist of an ion exchange resin membrane encased in plastic (Western Ag Innovations Inc. 2007). When the probes are buried in the soil, they measure the nutrient supply rates available to plants by adsorbing ions across the membrane over the probe burial length over time. PRS probes were installed on the 26th and 27th of May. The probes were pushed by hand at a 45° angle into the soil, until they were completely buried and only the ribbon tied to the end was visible. Once pushed into the soil, the soil on top of them was pushed down by hand to ensure good contact with the membrane. Probe pairs (cation/anion) were installed in each of the 192 vegetation survey plots. They were installed just outside of the sample plots on the upslope edge of the plots, instead of inside them to ensure that the plots were not disturbed. The probes were removed on August 26, 2010, after a three month burial period. In the lab, the probes were given a thorough cleaning with de-ionized water. Once thoroughly washed, the probes were shipped to Western-Ag Innovations for analysis. The data provided by the analysis corresponds to the supply rate of nutrients measured in units of micrograms / 10 cm/ over, in our case, the three month burial length for: Total N (based on the sum of NO_3^--N and NH_4^+-N), Ca, Mg, K, P, Fe, Mn, Zn, B, S, Pb, Al, and Cd (Western Ag Innovations Inc. 2007).

Understory vegetation sampling

The vegetation survey took place between August 6 and 11, 2010. In each of the 192 subplots (1m^2) the percentage cover of each species and an estimate of the number of individual plants of each species were recorded. Only vascular plant species were recorded. Percent covers of species were estimated to the nearest percentage for covers less than 10%, and to the nearest 5% for percentages higher than 10%. A cardboard cutout representing 1% cover of the plot was used and the same researcher made all the cover estimates to increase precision of the estimates. The number of individual plants (or the number of clumps for species with multiple stems) belonging to each species within the plot was assigned to one of three categories: category 1 for 1-5 stems, category 2 for 6-14 stems, and category 3 for $\geq$ 15 stems. This second method for estimation of relative abundance by species was used to facilitate comparison with the vegetation assessments done the previous September at the donor site (see also Chapter 2). Where possible, species were identified in the field. If a species could not be identified in the field, pictures were taken and it was transported back to the lab where it was pressed and identified using additional tools (herbarium, taken to experts in plant identification, etc.). Species nomenclature follows the online plant database of United States Department of Agriculture (USDA, 2010). There were two graminoid species that could not be identified because they did not flower. These were recorded as "unknown grass species" and "unknown sedge species".

Statistical analysis

The plant species identified in the vegetation survey were categorized into functional groups in three different ways. The first was by life-form: shrub, forb, or graminoid (as per USDA 2010). The second was by original distribution: species which had their origin in Canada (native) or species non-native to Canada (introduced) (as per USDA 2010). The third categorization was by life history of the species: either perennial or annual/biennial (as per USDA 2010). For statistical analyses, cover values for seeded cover crop species (barley, sweet clover, and fireweed) were excluded and these species were not included in estimates of richness or species abundance. Species were considered "uncommon" if they were present in less than 10% of the sample plots or if there were fewer than four individual plants in total found on the reclamation site. For statistical analysis, the stem counts described above were converted into midpoints in the following manner: abundance category 1 was converted to 3 individual plants, category 2 was converted to 10 individual plants, and category 3 was converted to 20 individual plants.

Univariate data analyses

The field study was setup as a split-plot with multiple blocks. Data from the four $1m^2$ subplots in each plot were averaged to create one value for the whole plot, so data analysis was based on the 48 plots. Univariate response variables (total vascular plant cover, cover by functional group, total species abundance, species abundance by functional group, and bioavailable soil nutrients) were analysed using ANOVA with depth treatment as the main plot (fixed effect) and cover crop as the split-plot (fixed effect) with block included as a random term. Cover crop was included in the model as a fixed effect and, as mentioned above, the cover crop species excluded from the response variable dataset. The statistical model used was:

$$Y_{ijk} = \mu + B_i + D_j + C_k + DC_{jk} + e_{ijk}$$

Where Y_{ijk} is the response variable, μ is the overall mean, B_i is the i^{th} block (random term), D_j is the j^{th} depth (fixed effect), C_k is the k^{th} cover crop (fixed effect), DC_{jk} is the interaction between depth and cover crop, and e_{ijk} is the residual error (random term).

Before proceeding with the ANOVA tests, residuals were created and tested for normality and homogeneity of variance. All residuals had homogeneous variances, and most met the assumption of normality. Some variables were not normal and transformations were not successful in bringing the residuals any closer to normality, such as for graminoid species abundance and total soil N and P availability. The distribution of the residuals of these data was carefully examined to ensure that the data were not strongly skewed in either direction. In all variables the residuals did not show a strong skew, thus the analysis was performed on the untransformed data, with the assumption that the Blocked Split-Plot ANOVA test was robust to minor deviations from normality. Some variables showed deviations from normality but data transformation using a natural log transformation was successful in achieving a normal distribution of the residuals; in these cases data analyses were conducted on the transformed data.

When the analysis was conducted, results of the Type III Test of Fixed Effects were examined to determine if depth and cover crop had a significant effect, and if there was a significant interaction between depth and cover crop. Cover crop never had a significant effect and so differences between the cover crops were not explored further, except for in one instances when there was a significant interaction between cover crop and depth. In that instance, contrasts were run to compare the two depth treatments for each cover crop separately and among the cover crops for each depth separately. To further explore the one significant interaction between depth and cover crop, an ANOVA was run to compare the percent cover of sweet clover on only plots that had been seeded with sweet clover between the two depth treatments (using percent cover of sweet clover as the response variable, depth as the fixed effect, and block as the random factor). These analyses were completed using proc mixed SAS 9.2 and α was set at 0.05.

Multivariate data analyses

To examine variation in species composition in relation to the two depth treatments, a Nonmetric Multidimensional Scaling (NMDS) ordination was run. The ordinations were run on species abundance data that were transformed to represent a relative abundance of plants at each plot (each species as a percentage of the total number of plants at each plot). Ordinations were performed using PC-ORD version 4. The starting configuration was set to random and the stability criterion was 0.0005; the Sørenson (Bray-Curtis) distance measure was used. Initially, I did 10 trial runs with real data, then using the results of Monte Carlo tests and the instability and stress values, the ideal dimensions for the ordinations were chosen. Three dimensions showed the best combination of low values for stress and instability, so 3D solutions were chosen for the final ordination. A final ordination was then performed using the output from the initial trial runs as the input for the final solutions. A Monte-Carlo simulation was used to test the significance of the ordination. The final solution had a total number of iterations of 130. Plots of stress vs. iteration were used to determine the final instability value of all ordinations, which was 0.005. The resulting ordination diagram displayed the species compositions of each plot, coded by the 15 cm and 40 cm depth treatments.

3.4 Results

Impact of salvage and placement depth

Salvage and placement depth were significant for many of the measured variables, but cover crop never had a significant effect except for in one instances when there was a significant interaction between cover crop and depth (Table 3-1 and 3-2).

Species abundance (per 1 m^2) in the 15 cm treatment was significantly higher when compared with the 40 cm treatment for all species combined and for every functional group category (all response variables) (Table 3-3). Percent cover for each functional group category was also significantly higher in the 15 cm than in the 40 cm treatment (Table 3-3). For all species combined, there was a significant effect of depth treatment and a significant interaction between depth treatment and cover crop (see below). The total understory species richness at the reclamation site, based upon the 192 subplots of 1 m^2 across both depth salvage treatments was 73 (four graminoids, 59 forbs, and 10 shrubs) (Table 3-4). Forty-nine species were native and 24 were non-native. Fifty were perennial and 23 were annual or biennial. Of the 73 total species found on the reclamation site, 38 species were uncommon.

At the 15 cm depth treatment, the total understory species richness based upon 96 subplots of 1 m^2, was 69 (four graminoids, 55 forbs, and 10 shrubs) (Table 3-4). Forty-six species were native and 23 were non-native; 46 species were perennial and 23 were annual or biennial. At the 40 cm depth treatment, the total understory species richness based upon 96 subplots of 1 m^2 was 58 (four graminoids, 45 forbs, and nine shrubs) (Table 3-4). Thirty-nine species were native and 19 were non-native; 39 were perennial species and 19 were annual or biennial species.

The NMDS ordination indicated that the species compositions were very similar for the 15 cm and 40 cm salvage treatments (Figure 3-3). There were only 15 additional species that were present at the 15 cm plots compared to the 40 cm plots, and all of these species were uncommon. Similarly, there were four species present at the 40 cm plots that were not present at the 15 cm plots, all of which were uncommon as well.

The six most common and abundant species at the 15 cm plots consisted of one graminoid, three forbs, and two shrubs. Four of these species were native and two were non-native, and five out of the six species were perennial, while only one was annual (Table 3-4). These species were *Galeopsis tetrahit* L. (approximately 820 plants; 98% of plots), *Vicia americana* Muhl. ex Willd. (approximately 360 plants; 89% of plots), *Trifolium repens* L. (approximately 285 plants; 84% of plots), *Symphoricarpos albus* (L.) S.F. Blake (approximately 388 plants; 79% of plots), *Rubus idaeus* L. ssp. *melanolasius* (Dieck) Focke (approximately 231 plants; 73% of plots), and *Calamagrostis canadensis* (Michx.) P. Beauv. var. *canadensis* (approximately 335 plants; 58% of plots). Of the 69 total species found on the 15 cm plots, 37 species would be considered uncommon.

The six most common and abundant species found at the 40 cm reclamation plots was similar to those found at the 15 cm reclamation plots. These species consisted of four forbs and two shrubs. Five of these species were native and perennial, while one species was a non-native annual (Table 3-4). The species were *Galeopsis tetrahit* (approximately 494 plants; 89% of plots), *Vicia americana* (approximately 300 plants; 90% of plots), *Symphoricarpos albus* (approximately 315 plants; 77% of plots), *Rubus idaeus* (approximately 215 plants; 70% of plots), *Lathyrus ochroleucus* Hook. (approximately 178 plants; 59% of plots), and A*ralia nudicaulis* L. (approximately 197 plants, 56% of plots). Of the 58 total species found on the 40 cm plots, 30 species would be considered uncommon.

To summarize, the most common and abundant species at the 15 and 40 cm plots were very similar. At both treatments, *Galeopsis tetrahit, Vicia americana, Symphoricarpos albus,* and *Rubus idaeus* were amongst the most common and abundant species. Although *Trifolium repens* and *Calamagrostis canadensis* were not dominant at the 40 cm treatment, both species were still quite abundant (156 plants; 54% of plots for *T. repens*; 125 plants; 31.25% of plots for *C. canadensis*). *Lathyrus ochroleucus* was a dominant species on the 40 cm plots, and was also quite abundant on the 15 cm plots (229 plants; 70% of plots).

After one growing season both treatments had significant areas with no vegetation cover [75% at the 15 cm treatment and 79% at the 40 cm treatment (Figure 3-2)]. Surface soils in the 40 cm treatment had significantly greater availability of soil total nitrogen (N) and nitrate (NO_3-N) than the 15 cm treatment (Table 3-3). The only other significant results for bioavailable nutrients were for potassium (K), sulphur (S), and zinc (Zn), which were all higher at the 15 cm treatment than the 40 cm treatment (Table 3-5).

<u>Impact of cover crops</u>

In the first growing season, cover crops had overall no significant effect on plant species abundances, plant cover, or available soil nutrients (Table 3-1). No fireweed established in plots that were seeded with it and there were low percent covers of barley and sweet clover in plots seeded with those cover crops (Table 3-2). Despite this, fireweed was left in as a factor for the ANOVA because it was set up as a treatment. There was a significant interaction between depth and cover crop for percent cover of all species combined, although the cover crop main effect was not significant (Table 3-1 and 3-2). This interaction was the result of the sweet clover cover crop where total percent cover of all species was significantly higher in the 15 cm treatment compared with the 40 cm treatment, while there were no differences between depth treatments for the other cover crop treatments (Table 3-2). Based on the contrasts comparing cover crops for each depth the only significant difference was that at the 15 cm treatment sweet clover was significantly different than the three other cover crop treatments ($p = 0.0051$; Table 3-2). Further, the percent cover of the sweet clover itself was significantly higher in the 15 cm treatment than at the 40 cm treatment (5.5% vs. 1.5%, $p = 0.0030$).

3.5 Discussion

Impact of salvage and placement depth

Salvage and placement depth had a significant impact on vegetation cover and caused total species richness to decline by 19% from the 15 cm treatment to the 40 cm treatment. Salvaging and placing at greater depth resulted in much lower percent cover and species abundance in all categories. For cover of all species combined, the greater cover at the 15 cm depth appears to be largely due to the response in the plots which had sweet cover planted as a cover crop (the significant depth by cover interaction). However, when cover was examined for each functional group separately there was no interaction with cover crop and in every case cover was higher for the 15 cm treatment. In terms of species composition, both depths were very similar. Comparable observations were made in a study conducted in the Australian Jarrah forest that examined comparable salvage depths (10 vs. 30 cm) in the first year at the reclamation site, where seedling recruitment and species richness declined from the 10 cm treatment to the 30 cm treatment (seedling recruitment: 254 seedlings per 5 m^2 vs. 81; species richness: 22 vs. 16). Holmes (2001) also found a decrease in native plant density 18 months after placing cover soil salvaged from 30 cm to 10 cm depth on a reclamation site in South Africa. A study in the Alberta oil sands region found that there was no difference in species diversity between a 10 and 20 cm depth forest floor placement in the second year at the reclamation site (Mackenzie and Naeth 2009). However, their study found a decrease in percent cover and species abundance in every functional group from the 20 cm treatment to the 10 cm treatment, a result that contrasts with the results of our study. The difference in response suggests that salvaging and placing at shallow depths could also reduce the viability of propagules due to exposure and desiccation (Wachowski et al., unpublished data) or due to operational challenges of placing the thin materials (Mackenzie and Naeth 2009).

<u>Reasons for differences between the depth treatments</u>

A dilution effect is likely the most plausible explanation for the differences between the two depth treatments in our study. Numerous studies from a variety of different ecosystems have documented that the majority of seeds are found within the top 5 cm of the soil (Putwain and Gillham 1990; Koch et al. 1996; Rokich et al. 2000; Zhang et al. 2001). Mackenzie and Naeth (2009) found that in the Athabasca oil sands region, the seeds of boreal forest understory plants were found in significantly higher densities in the top 5 cm of soil than in the 6-10 cm soil layer. Thus when the top, seed-rich layer (top 5 cm) is mixed with the underlying, seed-poor layers during a salvage operation, the seed bank in the top layer will become "diluted" by the seed-poor soil (Putwain and Gillham 1990); further, when material is placed at a greater depth seeds may be buried too deeply to successfully emerge from the soil (Grant et al. 1996). Results of research based in western Australia and British heathlands also support this explanation by showing that the optimal burial depth for successful emergence of seeds is less than 2 cm, and emergence severely decreases when seeds are buried deeper than 5 cm (Putwain and Gillham 1990; Grant et al. 1996; Rokich et al. 2000). In another reclamation experiment in western Australia, Tacey and Glossop (1980) found that of all the seeds that germinated at the reclamation site, 93% emerged from the top 2 cm of the soil.

These effects likely explain why we found a decline in species richness as well as lower abundance and percent cover at the 40 cm treatment when compared with the 15 cm treatment. This may also provide insight as to why 15 uncommon species that were present at the 15 cm treatment were not found at the 40 cm treatment. It is possible that some of the uncommon species had fewer seeds stored in the seed bank to begin with, thus the combined effects of dilution and the possibility that seeds were buried too deeply with the 40 cm treatment led to a failure to emerge on the reclamation site (Grant et al. 1996).

The two treatment depths received a different amount of soil handling, which could also have caused differences in species percent cover and abundance between the depths. The 40 cm treatment was handled more than the 15 cm treatment due to the increased amount of material that had to be salvaged, transported, and spread. It has been well documented that increased soil handling can cause elevated propagule death (Koch et al. 1996; Mackenzie and Naeth 2007).

There were also differences in bioavailable nutrients between the two depth treatments. The 40 cm treatment had more total nitrogen and nitrate than the 15 cm treatment, but less potassium, sulphur, and zinc. It was surprising that the 40 cm treatment had higher nitrogen availability. It was expected that the 40 cm treatments would have decreased amounts of nitrogen due to the increased amount of mineral soil included with the greater salvage depth, which would dilute the nitrogen-rich organic soil (Mackenzie and Naeth 2009). Since PRS probes indicate nutrient supply rates to plant roots over a period of time, this result suggests that a lot of nitrogen was initially available in both salvage treatments while there was little competition from plants. However, over time, as more plants established and grew in the 15 cm salvage sites, the PRS probes had to compete for the nutrients with the roots, and therefore the amount of nitrogen and nitrate they accumulated was reduced, resulting in an overall lower nitrogen accumulation in the probes compared to the probes in the 40 cm salvage depth. Nitrogen is often a limiting resource for growth of forest plants (Riegel et al. 1991) and therefore they require more nitrogen than other nutrients. This may explain why there was more bioavailable potassium, sulphur, and zinc at the 15 cm sites. These nutrients were less diluted with mineral soil at the 15 cm sites, and they were less affected by competition from roots than nitrogen was, so the availability of these nutrients did not decline over time.

Impact of cover crops

The results of our study indicate that in the first growing season the seeded cover crops had no effect on the development of the reclamation plant community. This was somewhat surprising, especially for barley which is widely used as a cover crop in reclamation because of its ability to grow quickly on a reclamation site and provide a vegetation cover (OSVRC 1998; Holmes 2001; Rowland et al. 2009). Cover crops were used in our study to provide a vegetation cover so that shade-tolerant species would have more of an opportunity to grow and compete with shade-intolerant ruderal species. If an effect of the cover crops had been found, it would have been expected that later successional species (for example, perennial species) would have had a higher cover and abundance in the cover crop plots as compared to the control plots, which was not the case in our study. In a typical reclamation area where the development of understory communities is not an objective, much higher seeding densities of barley (50 kg/ha) are being used (Woosaree and Hiltz 2011). When comparing the seeding rates used in our study to other typical seeding densities for mine reclamation projects in Alberta, it seems possible that the cover crops did not have an effect because they were seeded at too low of a density. In the future, it may be beneficial to increase the seeding densities of the cover crops in order to see their effects on the developing plant community.

It is also possible that there was no effect of the cover crops in the first year due to the autecology of sweet clover and fireweed. Sweet clover is a biennial species, meaning that they only produce small plants in the first year and do not produce seed until the second year (Ogle et al. 2008). Therefore, it is likely that in the second year, when these species produce seed, they will form a much more prominent vegetation canopy, and the effects of the canopy on other understory species may be significant in the second year. Fireweed is a perennial species that can reproduce by seed, and vegetatively through shoots from perennial rhizomes (Doak 1991). Perennial species originating from seed grow much slower than individuals recruiting from rhizomes. Therefore, it is possible that in the first year fireweed did not develop strongly enough to affect the plant community, and might be more dominant in the second year as it resprouts from its rhizomes and becomes more abundant on the site and forms a more pronounced canopy. However, as there was no cover of fireweed in plots in which it had been seeded, it is probable that no effect was found because the seeding method was not successful. It is possible that the seeds were washed or blown off the plots, or that they did not germinate or germinated too early in the season and did not survive to the end of the growing season. It will be important to monitor the plots seeded with fireweed in future years to determine if fireweed does begin to establish if it will eventually have an effect on understory plant development.

There was a higher percent cover of sweet clover at the 15 cm treatments as compared to the 40 cm treatments, which resulted in a higher cover of all other species. So in this case, it appears that sweet clover was effective as a cover crop and may have facilitated the establishment and growth of other species in the plant community instead of crowding them out by competition. The desired effect of the cover crops was to provide a vegetative cover to allow shade-tolerant less competitive species to grow with reduced competition from shade-intolerant ruderal species. However, at this early stage of development in the plant community, there was no good evidence that certain species were being favoured by the cover crop while other species were being shaded out. It is possible that the sweet clover had a positive effect on cover for the entire plant community at the 15 cm treatment because it provided better conditions for all plants. For example, it could have improved the microclimate, or affected the soil in a way in which it was able to hold more moisture, such by improving soil filtration, which in turn could have favoured the growth of all the plants growing with the sweet clover. However, when the effects of sweet clover and the other cover crops were examined separately for each functional group, this facilitative effect disappeared.

It is important to note that these data represent only the first year of growth at the reclamation site. In the years to come, it will be important to note how the species abundances and percent covers of the vegetation, as well as the cover crops, change in relation to one another and for the two treatment depths.

Effectiveness of forest floor transfer

Seventy-three species emerged at the reclamation site in the first year of growth; of these, 20 native, perennial species were found in the aboveground vegetation of the original donor site (Chapter 2). This indicated that the forest floor transfer method has the potential to facilitate establishment of a species-rich understory plant community at reclamation sites. Many of the species found on the reclamation site were annual (23 species) or non-native (24 species) early successional or ruderal species and represented a recently disturbed / very early successional plant community. However, this could be expected, given that the reclamation site had undergone a significant soil disturbance (Grime 1977). There were also 49 native and 50 perennial, later successional species that emerged at the reclamation site, which indicates that it has the potential to have a later successional understory plant community composition in future years. Results of a study carried out by Mackenzie and Naeth (2009) in the central mixedwood region of Alberta found similar proportions of native to non-native (0.7 native species found in their study and ours) and perennial to annual / biennial species (0.9 perennial species in their study vs. 0.7 perennial species in our study) at their 20 cm treatment reclamation site (see Chapter 2). They concluded that because this reclamation method makes viable propagules available on a reclamation site, it has the promise to help reclamation sites develop into communities that are similar to undisturbed upland forests. Our results indicate that in the future, this reclamation site has the potential to follow a similar successional trajectory; however, this will depend on the development of a tree canopy that would favour the more shade-tolerant understory species while shading out the early successional species from the community.

<u>Early post-reclamation site conditions</u>

The depth treatments were quite similar in terms of the species composition, although there was a difference in the amount of ruderal species at the depth treatments. The 15 cm treatment had six ruderal species that were not present at the 40 cm site, and four of the dominant species were ruderal (as compared to only two at the 40 cm site). However, although the 40 cm depth treatment had fewer dominant ruderal species, the overall species compositions of the two depth treatments were so similar that neither would be considered a more "natural" native understory forest composition than the other.

In the boreal forest, it is typical for native ruderal species to dominate after a disturbance of this scale, where resources (sunlight and nutrients) are abundant (Hart and Chen 2006). *Rubus idaeas* and *Calamagrostis canadensis*, two native ruderal, shade-intolerant, nutrient-demanding species that were dominant at the reclamation site in our study are often found in recently disturbed boreal forest communities because of their ability to grow quickly on these resource-rich sites (Hart and Chen 2006). However, after aspen canopy closure occurs, less than 10% of light will reach the forest floor, and early successional species like *R. ideaus*, *C. canadensis*, and *Chamerion angustifolium* (all of which were present at both depth treatments in our study) will greatly decline in abundance as more shade-tolerant, later successional species being to dominate the site (De Grandpré et al. 1993; Lieffers and Stadt 1994; Hart and Chen 2006). Therefore, it seems that although native ruderal species are dominant at the reclamation site now, particularly at the 15 cm treatment, they will naturally decline in abundance and have a lesser impact on the development of the plant community as the community transitions from dominance by ruderals to dominance by later successional species that are better adapted to growth under an aspen canopy.

There were however, some non-ruderal dominant species at the reclamation site that will likely have an impact on the longer-term development of the plant community. At the 15 cm and 40 cm treatments, *Vicia americana*, a nitrogen-fixing species, was dominant, while at the 40 cm treatment, *Lathyrus ochroleucus*, another nitrogen-fixer, was dominant as well (Bailey et al. 1998). These nitrogen-fixing species have the ability to alter the abitotic environment, and therefore these species might have a large influence upon the community development (Chapin et al. 2000).

While many of the species that were present at the reclamation site in the first year will have a significant impact upon development of the community at this early stage of succession (for example by controlling the amount of light that reaches the forest floor and nutrient cycling), their influence will decrease as they become less dominant in later successional stages (Hart and Chen 2006). Therefore, although there were later successional species present on the site in the first year, these species have a lesser impact on the development of the site at its current stage in succession. They will, however, be important in setting the stage for the future successional development of the community, as they represent the species that may become dominant in later successional stages.

Another condition that may have a large impact on the development of the plant community at the reclamation site is the amount of open and bare ground. Although plant cover was somewhat lower at the 40 cm treatment than at the 15 cm treatment, there was more than 60% of the area unoccupied by plants, leaving more space for the colonization of species from neighbouring areas. There is a possibility that in agricultural areas such as this, non-native, ruderal species (particularly grasses) which are aggressive colonizers in early stages of succession (Grime 1977) could colonize the open patches and come to dominate the developing community. Data from future growing seasons will be required to determine what type of plants are colonizing these bare areas to determine their longer-term impacts.

Management implications

The salvage and placement depth can significantly affect the development of plant communities of a reclamation site. Determining the desired salvage depth will be largely driven by the goal of the reclamation project. Despite the 40 cm depth having a lower species abundance and percent cover than the 15 cm depth in most cases, the species compositions were very similar. However, if the only reclamation goal is to quickly achieve high plant cover, abundance, or richness, or to control costs of materials handling and transport, it may be advantageous to use the 15 cm depth.

Although no effect of cover crops was found in the first year, there is a possibility that in the second year as the plants grow larger and reproduce, they will have an effect on the development of the plant community at the reclamation site. It would be advantageous to examine their development into the future to make more definitive conclusions about seeding rates or the species used.

It is important to note that the goal of this study was specifically to test the response of understory species, so trees were not included. However, establishing trees on the reclamation site would obviously be a goal of any forest reclamation project. Therefore, other components of forests must also be considered when choosing a salvage and placement depth for forest floor transfer. In addition to the understory establishment, the same experiment also focused on the establishment of aspen (*Populus tremuloides* Michx.) from root segments in these salvaged soil. Preliminary results indicate that the 40 cm salvage depth treatment had greater aspen sucker establishment from the root propagules and their growth was better than for the 15 cm salvage depth (Wachowski et al., unpublished data).

3.6 Conclusions

To effectively reclaim a functional boreal forest ecosystem, the understory community must be actively reclaimed as well. Mining operations previously focused on tree establishment and paid little attention to understory recovery. Initial reclamation of understory communities used forest surface soil that had been kept in stockpiles for sometimes up to decades and this resulted in very few viable propagules being available in that surface soil. The forest floor transfer method can aid in re-establishing a functional understory forest plant community on reclamation sites by providing viable native plant propagules to these sites. Although in the first year of growth, the plant community at the reclamation site will have an early successional species composition, it has the potential to develop into a later successional forest understory resembling that of the donor site in future growing seasons. Salvaging and placing the material at a depth of either 15 or 40 cm can both result in a species-rich understory community, although the material that was salvaged deeper will usually result in somewhat lower percent cover and species abundance. When this method is implemented operationally, the salvage and placement depths chosen will be a reflection of the goals of the reclamation project and will be driven by the conditions of the donor and reclamation site. The forest floor transfer method has the potential to be the leading understory reclamation technique as it is effective at introducing and allowing native understory plant propagules to establish at the reclamation site, therefore allowing the site to rapidly achieve a species-rich understory community.

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Tables

Table 3-1. Results of ANOVA examining treatment effects on species abundance, cover and soil nutrient availability. Given are P-values for the effect of depth (d.f.= 1), cover crop (d.f.= 3), and depth by cover crop interaction (d.f.=3). (Block d.f=5, depth*cover crop*block d.f.=15, residual error d.f.=20). P-values in bold are significant at α = 0.05.

Response Variable	Depth	Cover Crop	Depth*Cover Crop
Species Abundance			
All species	**<0.0001**	0.8265	0.4718
Native	**0.0059**	0.4203	0.6592
Non-Native	**0.0003**	0.3541	0.4538
Perennial	**0.0003**	0.2362	0.8405
Annual/Biennial	**0.0173**	0.3816	0.1598
Forb	**0.0018**	0.9427	0.5290
Shrub	**0.0054**	0.4951	0.6650
Graminoid	**0.0399**	0.3531	0.5655
% Cover			
All species	**0.0127**	0.4539	**0.0421**
Native	**0.0194**	0.3623	0.1935
Non-Native	**0.0001**	0.8241	0.5728
Perennial	**0.0007**	0.4985	0.0732
Annual/Biennial	**0.0111**	0.7427	0.5801
Forb	**0.0009**	0.8082	0.5430
Shrub	**0.0226**	0.3027	0.0683
Graminoid	**0.0002**	0.5504	0.3645
Bioavailable Soil Nutrients			
Total N	**0.0116**	0.5634	0.4032
NO^{-}_{3}-N	**0.0003**	0.4721	0.3904
NH^{+}_{4}-N	0.0941	0.5654	0.8611
K	**<0.0001**	0.8297	0.5816
P	0.0506	0.8468	0.0847
S	**<0.0001**	0.5223	0.7063
Ca	0.2202	0.2469	0.5171
Mg	0.3253	0.6822	0.5841
Fe	0.5937	0.2370	0.3582
Mn	0.7867	0.8083	0.7443
Zn	**0.0024**	0.1690	0.4317
B	0.0881	0.2740	0.1357
Pb	0.3348	0.7625	0.8241
Al	0.2681	0.9585	0.2968

Table 3-2. Mean percent cover for all species combined (excluding species seeded as cover crops) by Depth and Cover Crop treatments exploring the significant interaction between the two treatment effects (see Table 3-1). Within a column, values followed by different superscript letters show significant differences between cover crops; * indicates there was a significant difference between the two depths for only the Sweet Clover cover crop treatment. ($\alpha = 0.05$). Part B shows the mean percent cover for the cover crop treatment species only on the plots they were seeded in.

Cover Crop	15 cm Depth	40 cm Depth
Barley	23.5[a]	22.2 [a]
Sweet Clover*	31.9 [b]	18.5 [a]
Fireweed	23.8 [a]	18.8 [a]
Control	21.8 [a]	22.6 [a]
% Cover of Seeded Cover Crop		
Barley	2	4
Sweet Clover	6	1
Fireweed	0	0
Control	-	-

Table 3-3. Comparison of species abundance (mean number of plants per 1m² subplot) for all species combined and for different functional groups between the 15 cm and 40 cm treatments. Based on the split-plot ANOVA there was no significant effect of cover crop and only one cover crop by depth interaction (Table 3-1 and 3-2). Effects of depth only are as shown below. P-values in bold are significant at $\alpha = 0.05$.

Species Category	15 cm			40 cm			P-value
	Mean	Lower 95% C.I.	Upper 95% C.I.	Mean	Lower 95% C.I.	Upper 95% C.I.	
All Species	27.7	26.0	29.4	23.0	21.5	24.5	**<0.0001**
Native	19.3	17.9	20.7	16.5	15.2	17.7	**0.0059**
Non-Native	8.5	7.7	9.3	6.5	5.7	7.3	**0.0003**
Perennial[1]	19.0	17.7	20.3	15.5	14.4	16.5	**0.0003**
Annual / Biennial	8.8	7.9	9.6	7.5	6.6	8.4	**0.0173**
Forb	20.6	19.0	22.1	17.1	15.8	18.4	**0.0018**
Shrub[1]	4.6	4.2	5.0	3.6	3.3	4.0	**0.0054**
Graminoid	2.6	2.5	2.8	2.3	2.0	2.4	**0.0399**

[1]Data tested were natural log transformed.

Table 3-4. Species richness (# species encountered based on sampling of 96 1m^2 subplots in each depth treatment) for all species combined and by plant functional group at the reclamation site for each depth treatment separately (15 cm and 40 cm) and for both depth treatments combined. The number of species in each functional group that dominated each depth treatment (out of a total of six dominant species at each treatment) and the number of species in common between the two depth treatments is also shown**.**

	15 cm Depth		**40 cm Depth**		**Reclamation Site Total**	
Plant Group	**# of Species**	**# of Dominant Species**	**# of Species**	**# of Dominant Species**	**Combined Depths**	**# Species in Common**
Total	69	-	58	-	73	54
Graminoids	4	1	4	0	4	4
Forbs	55	3	45	4	59	42
Shrubs	10	2	9	2	10	8
Annuals / Biennials	23	1	19	1	23	19
Perennials	46	5	39	5	50	35
Natives	23	4	19	5	49	16
Non-natives	46	2	39	1	24	38

Table 3-5. Comparison of soil nutrient supply rates (micro grams/10 cm/three month burial length) between the 15 cm and 40 cm depth treatments. Based on the split-plot ANOVA there was no effect of cover crop and no cover crop by depth interaction (Table 3-1). Effects of depth are as shown below (from Table 3-1). P-values in bold are significant at α = 0.05.

Soil nutrient	15 cm			40 cm			P-value
	Mean	Lower 95% C.I.	Upper 95% C.I.	Mean	Lower 95% C.I.	Upper 95% C.I.	
Total N	14.3	10.3	18.3	26.1	18.4	33.8	**0.0116**
NO_3-N[1]	9.4	5.7	12.5	20.4	13.0	28.3	**0.0003**
NH_4-N	5.0	4.0	5.9	5.7	4.9	6.5	0.0941
K[1]	64.7	58.8	70.5	44.7	41.3	48.0	**<0.0001**
P[1]	8.6	6.0	11.2	6.3	4.3	8.3	0.0506
S[1]	606.5	489.3	723.8	206.0	169.1	243.0	**<0.0001**
Ca	2897.5	2817.8	2977.3	2949.4	2876.8	3022.0	0.2202
Mg	329.4	318.8	340.0	337.2	325.3	349.0	0.3253
Fe	73.9	60.6	87.1	70.0	59.6	80.3	0.5937
Mn[1]	4.7	3.9	5.5	4.6	4.1	5.2	0.7867
Zn[1]	8.7	7.1	10.3	5.8	4.7	7.0	**0.0024**
B[1]	2.5	2.2	2.8	2.2	2.0	2.4	0.0881
Pb[1]	1.0	0.8	1.1	0.9	0.7	1.0	0.3348
Al[1]	40.4	37.9	42.9	38.7	36.9	40.4	0.2681

[1]Data tested were natural log transformed.

Figures

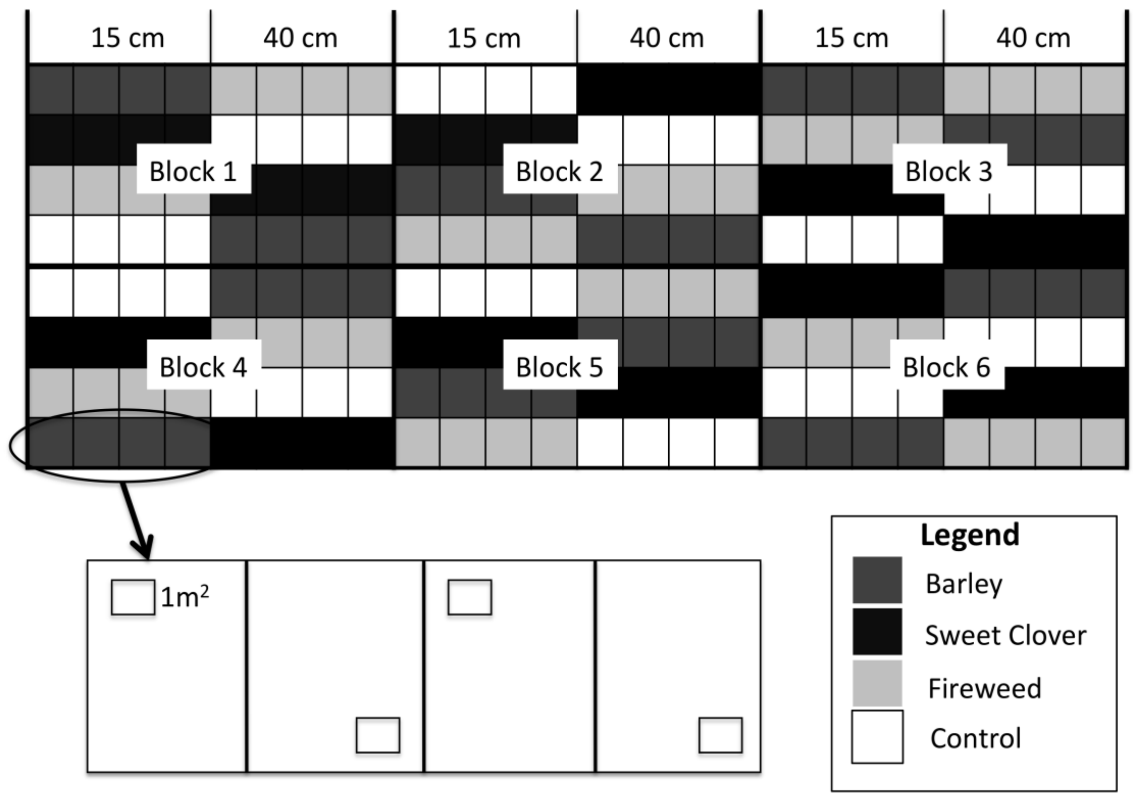

Figure 3-1. The reclamation site experimental set-up consisted of six experimental blocks, each of which received both depth treatments. Cover-crop treatments were set up as split-plots within the depth treatments. Within each block and depth plot, the area was divided into four plots that were randomly assigned to one of the four cover crop treatments. Each of the four plots was subdivided into four equal-sized subplots, in which one permanent quadrat (1 m^2) was set up for vegetation and nutrient sampling (n = 192).

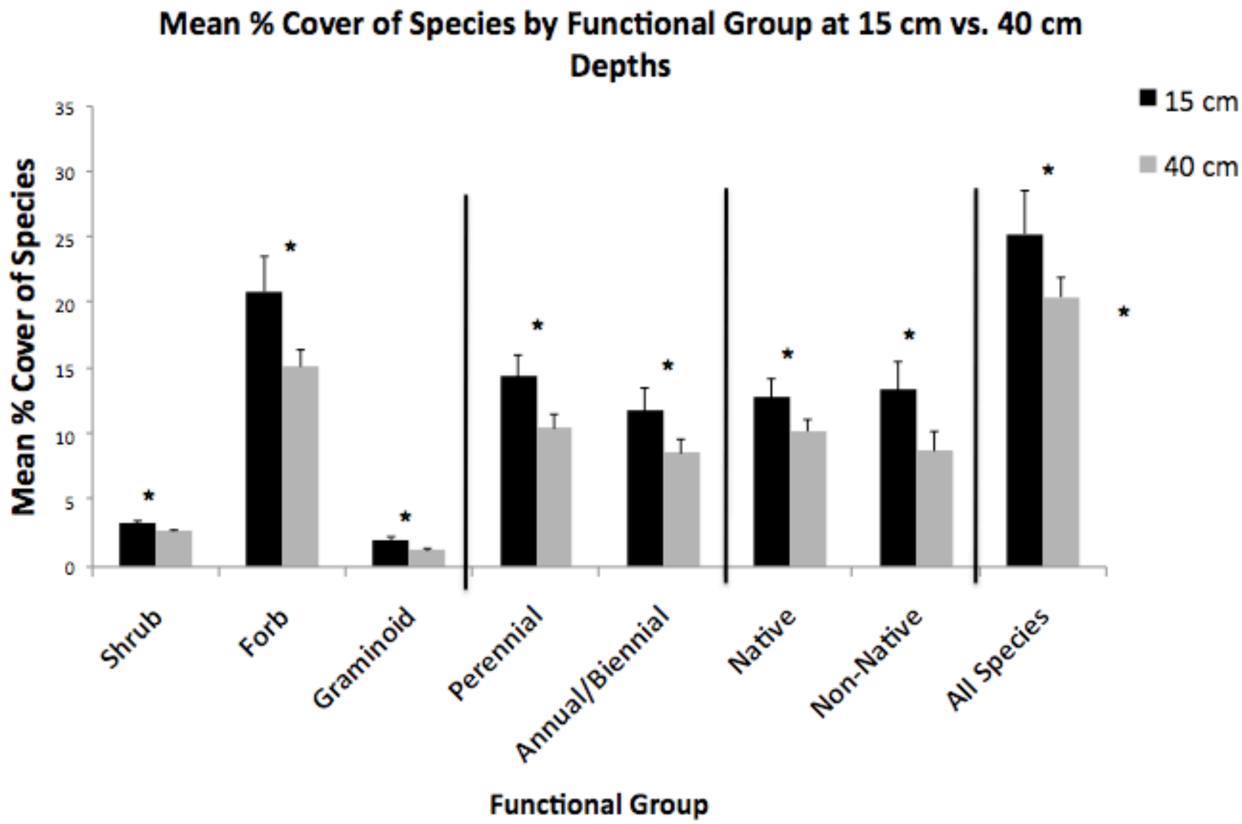

Figure 3-2. Mean percent cover of species by functional group at 15 cm vs. 40 cm depth treatments (α = 0.05). Based on the split-plot ANOVA there was no significant effect of cover crop and no significant cover crop by depth interaction (Table 3-1). Effects of depth are shown: * Indicates significant differences.

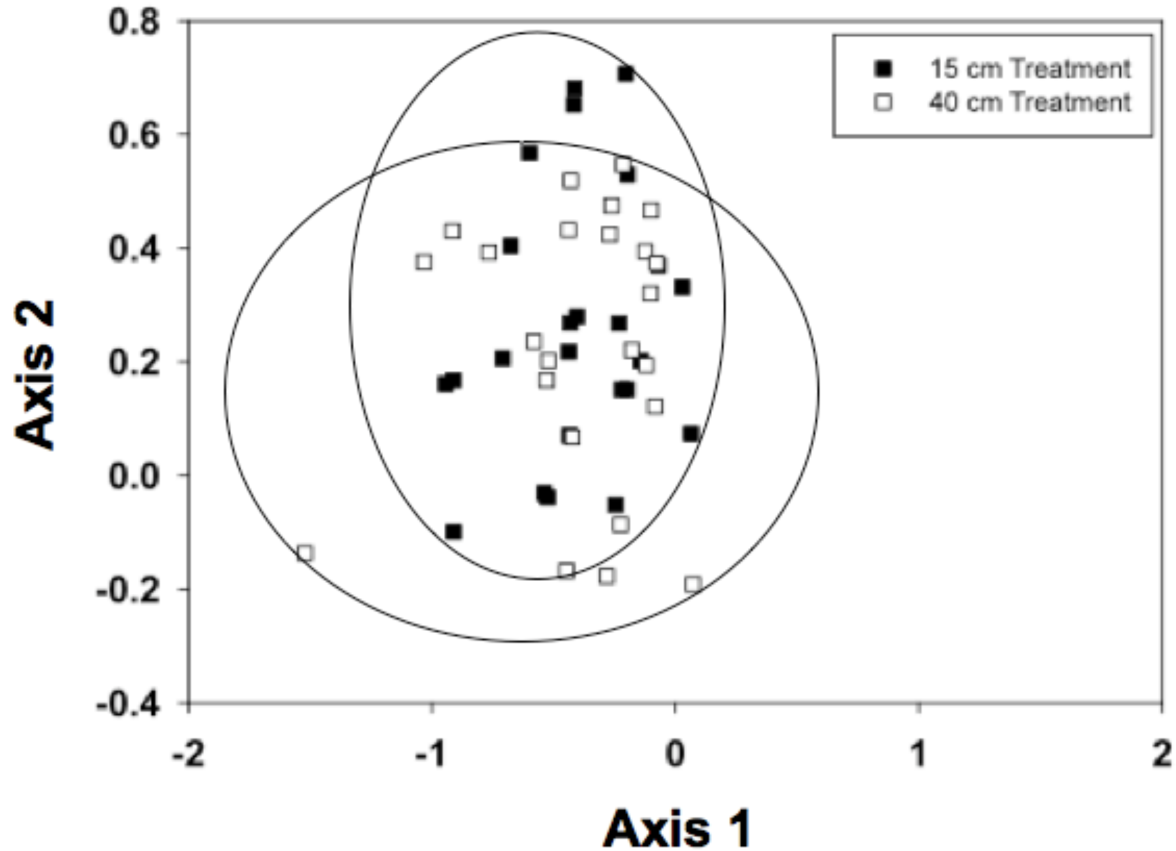

Figure 3-3. Results of NMDS Ordination based on plant community composition at the reclamation site. Each point represents a subplot of either the 15 cm or 40 cm depth treatment. The ordination shows how similar the subplots are to each other based on the species composition (which species and their relative abundances).

Chapter 4: Summary and Implications

4.1 Effectiveness of forest floor transfer method

The objective of the forest floor transfer reclamation method is to facilitate native plant species establishment on reclamation sites. My results provide some evidence that this method can be effective for this purpose. A total of 73 vascular understory species were found at the reclamation site in the first year of growth after the forest floor transfer, 49 of them native species, 41 of which came from the donor site. While the species composition of the reclamation site in the first year resembled that of a recently disturbed or very early successional site - with 32% of species annual or biennial and 33% non-natives - there were many later successional species present at the reclamation site as well. This indicates that in the following growing seasons, the reclamation site has the potential to develop into a later successional understory plant community, similar to that of the donor site. This is likely largely attributable to the fact that the forest floor transfer method was able to provide viable propagules of native plant species to the reclamation site. This is a particular advantage for large open-pit mines in the boreal mixedwood region because in these locations there are often few nearby sources of propagules for native forest species.

There are no additional financial costs associated with this reclamation method, as materials are moved only once compared to stockpiled materials; however, there is additional time required to organize and coordinate such an operation. However, when considering the potential of the forest floor transfer method to facilitate more rapid establishment of native species on a reclamation site, a feat that cannot be easily achieved through any other known technique at this point, it is clear that the ecological benefits could well outweigh the costs.

However, it is important to note that the forest floor transfer method is not relevant or applicable to all reclamation projects or ecosystem types. For example, a very old growth forest would not make a good donor site for this method as there are very few understory vascular plants, and many of the seeds in the seed bank may be too old to still be viable. Therefore, this method should only be employed in situations in which there is a suitable donor site available, one that consists of many native, desirable understory plants for re-establishment at the reclamation site. Further, the donor site in our study was surrounded by agricultural land, and therefore the seeds of many agricultural or weedy species were contained in the seed bank. This likely affected the plant community that established at the reclamation site, and a donor site that was surrounded by more natural areas would likely have transferred a very different species assemblage to the reclamation site. The donor site had been harvested 11 years prior to the study, which also would have had an effect on which species were present on the site and in the seed bank. An older forest that had not undergone harvesting so recently would have a different species and seed bank composition to transfer to the reclamation site. Therefore, when employing the forest floor transfer method, it is important to be aware that the plant community that establishes on the reclamation site will be a reflection of the conditions of donor site used and the surrounding areas.

Comparison of donor site and reclamation site plant communities

The understory plant composition of the donor site represented the potential species that could be transferred to the reclamation site. The two components of the donor site, the aboveground vegetation and the seed bank, when combined, demonstrated the potential for an early- to later-successional understory plant community. The aboveground plant community consisted of 31 native species that would be desirable for the revegetation of the reclamation site. In the first growing season after the forest floor transfer took place, the reclamation site contained 20 of these species along with an additional 21 species contained in the donor seed bank. There were 32 species gained at the reclamation site that likely came from neighbouring sites (or they were present at the donor site but not detected in our vegetation surveys). Both early and later successional species were present at the reclamation site, although it was dominated by early successional species.

The results of this study were based on only the first year of data from the reclamation site, when the site would be expected to be in the early stage of succession following such a severe soil disturbance. Although the understory plant community at the reclamation site was dominated by more ruderal species than would normally be found after a natural disturbance (such as fire), the site also hosted a large number of later successional native forest species that puts it in a good position to continue along a successional path towards a more natural forest understory community.

Salvage and placement depth

The 15 cm salvage and placement depth resulted in higher species abundance and percent cover than the 40 cm treatment in most cases, which is likely attributable to the higher concentration of plant propagules in the surface soil layers. Despite this, the species compositions were very similar for both treatment depths, mainly dominated by ruderal species (especially the 15 cm treatment). However, it is likely that the ruderal species present in the first seasons of growth will not have a long-lasting effect on the development of the forest community. This is because as overstory cover develops, growing conditions will change on the site and this is likely to cause a shift in dominance from early successional, shade-intolerant species to later successional, shade-tolerant species. Therefore, it is obviously important to establish a tree cover at the reclamation site to promote the development of a more natural boreal forest plant community.

It must be noted that the 15 and 40 cm salvage and placement depths are not “optimal” depths. Rather, these depths were chosen specifically because they were appropriate for the conditions at our donor site. For other reclamation projects, salvage depths must be chosen based on the conditions present at the donor site. For example, if a heavy clay layer is present at a depth of 25 cm at a donor site, it would not be advisable to salvage any deeper than this, as the clay would degrade the quality of the overlying forest floor material. Therefore, it is not always advantageous to salvage deep in order to have more forest floor material, and salvage depths must be chosen carefully in accordance to the conditions at the donor site.

4.2 Definition of "success"

There are many ways in which the success of reclamation projects can be measured, dependent upon what each project sets out to achieve. Therefore, it is important when undertaking reclamation projects to carefully outline the goal(s) of the project. Some potential goals relating to this reclamation technique could include: establishing a diverse and high percent cover of native understory plants, controlling ruderal and undesirable species establishment, controlling reclamation costs, or a combination of all three. Success relating to each of these goals would be measured by different criteria: either by the species percent cover or richness achieved at the reclamation site, by the number of ruderal or non-native species that established, or finally by the cost of carrying out the project.

The goal of this reclamation project was to facilitate the establishment of native forest understory species on the reclamation site, and therefore the percent cover and total number of native understory species that established on the reclamation site should be the criteria that are used to judge the success of this project. In this regard, this project could be considered a "success" as a total of 49 native understory species with a mean percent cover of 11.6% established on the reclamation site in the first year of growth. The same criteria can also be used to determine which salvage depth was most successful: the 15 cm treatment had 23 native understory species with a mean percent cover of 12.8% while the 40 cm treatment had only 19 native understory species establish with a mean percent cover of 10.3%. Therefore, if these are the only criteria upon which the success of the depth treatment is judged, than the 15 cm treatment would be considered more "successful". However, this would be a very narrow definition of success, and although the difference between the two depths is statistically significant, it may not be ecologically significant enough to determine that one depth is "more successful" than the other for this objective.

In reality, reclamation goals are never so simple. The other reclamation goals discussed previously must also be taken into consideration. If the goal of this project had been to achieve a high cover of all species, for example, this reclamation method may not have been considered so successful, as the mean percent cover achieved of all species (excluding seeded cover crops) was 25% on the 15 cm depth treatment and 21% on the 40 cm treatment. Achieving a high percent cover is an appropriate goal for reclamation projects as higher cover of understory vegetation can prevent soil erosion and hold on to soil moisture and nutrients (Whittle et al. 1997). Therefore, having such a low overall cover may negatively impact the future development of the plant community, and had this been the main goal for our project, it would not be considered "successful". This method could also be considered "unsuccessful" if the main goal had been to limit the establishment of undesirable, ruderal species on the reclamation site, as the site played host to and was dominated by many ruderal species. On the other hand, the direct forest floor transfer method has a cost-saving advantage because the material only has to be handled once to move it to the reclamation site, rather than stockpiling where material must be moved twice (to the stockpile then to the reclamation site).

Even though the direct forest floor transfer method had downsides, such as a low overall percent cover and high establishment of ruderal species, it also achieved a cost advantage and it established many native species. When implementing reclamation techniques operationally, all of these outcomes need to be considered in the decision to label the method a "success" or not.

It would also be important to determine a time limit over which to evaluate the performance of a reclamation site. The plant community present on the reclamation site in the first year may shift considerably in later years and this could influence how its success is evaluated. Therefore, it would be useful to continue to monitor the reclamation site over several years to determine if and when the reclamation project can be considered "successful".

4.3 Strengths and limitations of our study

Strengths

This project represented an operational-scale trial of an innovative reclamation technique, and our study had the ability to assess the effectiveness of carrying out this technique at this large scale, which has received very limited testing in previous research. While two studies on similar reclamation techniques have attempted to use equipment of the same size as in our study, both reported significant operational difficulties. Koch et al. (1996) attempted to use bulldozers to remove trees from sites of only 1 ha in size, and recounted that the bulldozers caused considerable damage to the soil surface. They also stated that they were not able to salvage to only 5 cm as originally planned because this was too difficult with the large machinery. Mackenzie and Naeth (2009) also had serious problems when spreading the forest floor material at the reclamation site with crawler tractors. The tractors caused significant admixing in the 10 cm application thickness that resulted in mineral soil being mixed-in with and diluting the forest floor material and leaving many bare patches that did not receive any material. Even studies that have attempted to use smaller machinery to salvage the forest floor material, such as scrapers, reported difficulties in the accuracy of their salvage operations (Tacey and Glossop 1980). Therefore, although this method has received limited testing at a large scale, all testing has recounted serious challenges in the operational portion of the process. In testing the direct forest floor transfer method at an operational scale, our study was able to identify ways in which to improve upon this method, which will be outlined below in Section 4.4. Our project was a realistic and applicable study of a reclamation method that has a lot of potential to be implemented at surface mines as a way to reclaim understory communities.

Limitations

Within the confines of this study, the effectiveness of this method cannot directly be compared to that of using stockpiled material. However, based on other research into the effects of stockpiling, our values for first-year percent cover and species richness were higher than that which has been found in other studies using stockpiled material (Tacey and Glossop 1980; Iverson and Wali 1982; Koch et al. 1996; Rokich et al. 2000). This can likely be attributed to the presence of more viable propagules present in the transferred material and thus on the reclamation site. In a study in the Australian Jarrah forest, Koch (1996) found that viable seeds decreased to 13% of the total found in the undisturbed forest floor after being kept in a stockpile for 10 months. This decrease in viable seeds is reflected in the results of Tacey and Glossop (1980) who found in a study in the same region of Australia that the species richness of a reclamation site that received stockpiled soil declined to 22 species, as compared to 35 for a site that had received forest floor transferred material. This limitation to our study is not a serious issue, however, as it is easy to understand why stockpiling is detrimental to propagule viability, and it is quite likely that had we been able to compare the results of the forest floor transferred material to stockpiled material, we would have found similar results to other researchers.

Another limitation of our study was the intensity of data collection. Only 17 m^2 of the entire 46,000 m^2 area of the donor site was surveyed, while 192 m^2 of the entire 46,000 m^2 reclamation site were surveyed. Therefore vegetation surveys of the aboveground donor site did not likely identify every species on the site and there is a good possibility that some aboveground species that were present at the donor site were not detected. In addition, this study focused only on vascular understory species. However, to truly determine the effectiveness of this reclamation method, other forest components such as more detailed soil properties, overstory vegetation, non-vascular vegetation, soil microbes, fauna, and the interactions between all of these components must be considered. Finally, this study was based upon only the first year of growth at the reclamation site. To accurately understand the outcome of the forest floor transfer method, the development of the reclamation site must continue to be monitored for many years into the future.

4.4 Management solutions and future research

The results of this study have identified aspects of the forest floor transfer method that could be improved in the future. Firstly, it would be beneficial to decrease the amount of handling that the forest floor material received in order to maintain the viability of as many plant propagules as possible. The results of this study also suggest that it may be advantageous to increase the cover crop seeding rate to ensure that cover crops are carrying out their intended function (creating a vegetative cover in the first few growing seasons at the reclamation site), as well as aiding in erosion control. Another improvement to the effectiveness of this method may be to seed or plant trees at the reclamation site. A developing canopy would create shade for the understory plants, and would cause the ruderal species to become shaded out and force a shift in dominance from early successional to later successional species which are more shade-tolerant (McCook 1994; Hart and Chen 2006). This could help accelerate the transition from a recently disturbed species composition to a later successional and more natural forest community.

It will also be important to continue monitoring the site in the future to better understand the development of the understory plant community on the reclamation site. This will be important as unexpected changes may occur that could have a large impact upon the plant community. For example, in a similar reclamation study by Holmes (2001) in South Africa, after three years of growth, there was a higher percent plant cover at the deeper (30 cm) placement than at the shallower placement (10 cm). Although currently at our reclamation site we have found the opposite result, it is possible that within three years our findings could mirror those of Holmes (2001), and therefore it will be important to continue monitoring into the future.

Future research should focus on treating the reclamation site as an entire ecosystem rather than as separate components making up an ecosystem. It will be important to focus on soil moisture, nutrients, microtopography, and microsites to determine their effects on the development of the forest community at the reclamation site. It will also be important to examine the development of the overstory. Other research into the forest floor transfer method at this same reclamation site has found that the 40 cm salvage depth had better aspen sucker establishment from root segments than the 15 cm treatment, but that suckers could not emerge when originating from roots buried at a depth greater than 20 cm (Wachowski et al., unpublished data). These results suggest that the optimal solution may be to salvage the forest floor to a depth of 40 cm, but spread it at a lesser depth (for example, 20 cm). In a similar reclamation project in western Australia, Grant et al. (1996) also suggested the idea of salvaging soil to a certain depth and spreading it thinner. This was presented as a solution to achieve higher seedling emergence for understory species as seedlings are severely impeded from emerging when buried deeper than 5 cm (Putwain and Gillham 1990; Grant et al. 1996; Rokich et al. 2000).

This approach of salvaging at a certain depth and spreading at a thinner depth would likely lead to different effects on the understory plant community than that which we observed, given that the propagule bank would be diluted once by mixture with the deeper, propagule-poorer layers and then again because less material is placed. Together, these dilutions would likely result in lower species cover, abundance, and richness than we saw for the 40 cm treatment. However, as the results of our research have shown, in the future, the 40 cm depth may develop into a community very similar to that at the 15 cm plots, and therefore a community that was salvaged at 40 cm and placed at 20 cm may have the potential to do so as well. Therefore, salvaging soil deeper and spreading it thinner is worth investigating as an approach to facilitate aspen suckering and to stretch the supply of the forest floor material in situations where insufficient material is available, as natural forest floor material is generally a limited and valuable resource in mining areas.

The Alberta government requires mining companies to return reclaimed land to the equivalent capability of the pre-disturbance land, and therefore this natural forest soil is a useful resource to achieve this because of its nutrient content (Alberta Environment 2006) and the propagule bank it contains. However, as development of land in the energy mining areas of Alberta continues to expand, either for agriculture, urban development, or the oil sands in the northern portion of the province, the store of this surface soil material is declining. Therefore, it is important to make the most of the forest floor material that is available to ensure that reclaimed forests can be returned to as natural a state as possible.

4.5 Literature cited

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Appendices

Appendix 2-1. List of species and which sites they were encountered at during the study.[1] * Represents species native to Canada (as per USDA 2010).

Species Name	Donor Site		Reclamation Site
	Above Ground	Seed Bank	
Achillea sibirica Ledeb.*			X[2]
Amelanchier alnifolia (Nutt.) Nutt. ex M. Roem.*			X[2]
Anemone parviflora Michx.*		X[2]	X
Aralia nudicaulis L.*	X		X
Bassia scoparia (L.) A.J. Scott			X
Brassica napus L.			X[2]
Bromus ciliatus L.*		X[2]	
Calamagrostis canadensis (Michx.) P. Beauv. var. *canadensis**	X	X	X
Canadanthus modestus (Lindl.) G.L. Nesom*			X[2]
Capsella bursa-pastoris (L.) Medik.		X[2]	X[2]
Cardamine pensylvanica Muhl. ex Willd.*		X[2]	
*Carex sp.**	X		
Chamerion angustifolium (L.) Holub ssp. *angustifolium**	X[2]	X	X
Chamerion latifolium (L.) Holub*			X[2]
Chenopodium album L.		X[2]	X
Chenopodium capitatum (L.) Asch.*		X[2]	X
Cirsium arvense (L.) Scop.		X	X[2]
Collomia linearis Nutt.*			X[2]
Cornus canadensis L.*	X	X[2]	
Cornus sericea L. ssp. *sericea**	X	X[2]	
Corydalis aurea Willd.*		X	X
Corylus cornuta Marsh.*	X[2]		
Crepis tectorum L.			X[2]
Elymus repens (L.) Gould			X
Elymus trachycaulus (Link) Gould ex Shinners ssp. *subsecundus* (Link) A. Löve & D. Löve*		X[2]	
Epilobium ciliatum Raf. ssp. *ciliatum**		X	
Equisetum arvense L.*			X
Equisetum scirpoides Michx.*			X[2]
Erigeron elatus (Hook.) Greene*		X[2]	
Erysimum cheiranthoides L.			X[2]
Eurybia conspicua (Lindl.) G.L. Nesom*	X	X[2]	X
Eurybia sibirica (L.) G.L. Nesom*			X[2]
Festuca altaica Trin.*	X[2]		
Fragaria vesca L.*	X	X	X

Species Name	Donor Site		Reclamation Site
	Above Ground	Seed Bank	
Galeopsis tetrahit L.		X	X
Galium boreale L.*	X	X2	X2
Galium triflorum Michx.*	X	X	X2
Geranium bicknellii Britton*		X2	X
Geum aleppicum Jacq.*		X	X2
Heracleum maximum Bartram*	X2		X2
Hieracium umbellatum L.*			X2
Lathyrus ochroleucus Hook.*			X
Lonicera dioica L.*	X		
Lonicera involucrata (Richardson) Banks ex Spreng.*	X		X
Lonicera tatarica L.			X2
Maianthemum canadense Desf.*	X		X2
Maianthemum stellatum (L.) Link*	X2		X2
Melilotus officinalis (L.) Lam.		X2	X
Mentha arvensis L.*		X2	X2
Mertensia longiflora Greene*			X2
Mertensia paniculata (Aiton) G. Don. var. *paniculata**	X	X2	X
Mitella nuda L.*	X		
Moehringia lateriflora (L.) Fenzl*		X2	X2
Petasites frigidus (L.) Fr. var. *palmatus* (Aiton) Cronquis*	X		X
Plantago major L.		X2	X
Polygonum arenastrum Jord. ex Boreau			X2
Polygonum convolvulus L.			X2
Potentilla norvegica L.*		X	X
Prunus pensylvanica L.f.*	X2		X
Prunus virginiana L.*	X2		X
Pyrola asarifolia Michx.*	X2		
Ranunculus cardiophyllus Hook.*			X2
Ranunculus lapponicus L.*			X2
Ribes hudsonianum Richardson*			X2
Ribes triste Pall.*	X	X2	X2
Rosa acicularis Lindl.*	X		X
Rubus idaeus L. ssp. *melanolasius* (Dieck) Focke*	X2	X	X
Rubus pubescens Raf.*	X		X
Salix petiolaris Sm.*			X2
Silene latifolia Poir. ssp. *alba* (Mill.) Greuter & Burdet			X2
Sinapis arvensis L. ssp. *arvensis*			X2
Solidago canadensis L. var. *gilvocanescens* Rydb.*		X2	

Species Name	Donor Site		Reclamation Site
	Above Ground	Seed Bank	
Sonchus oleraceus L.		X	X[2]
Spergula arvensis L.			X[2]
Stachys pilosa Nutt. var. *pilosa**			X[2]
Stellaria media (L.) Vill.		X[2]	X[2]
Symphoricarpos albus (L.) S.F. Blake*	X		X
Symphyotrichum laeve (L.) A. Löve & D. Löve var. *leave**		X	X
Taraxacum officinale F.H. Wigg.		X	X
Thlaspi arvense L.		X[2]	X
Tiarella trifoliata L.*			X[2]
Trifolium pratense L.			X[2]
Trifolium repens L.			X
Tripleurospermum perforatum (Mérat) M. Lainz			X
Typha latifolia L.*		X[2]	
Veronica peregrina L. ssp. *xalapensis* (Kunth) Pennell*		X	
Veronica scutellata L.*		X	
Viburnum edule (Michx.) Raf.*	X		
Viburnum opulus L. var. *americanum* Aiton*	X[2]		
Vicia americana Muhl. ex Willd.*		X[2]	X
Viola canadensis L. var. *rugulosa* (Greene) C.L. Hitchc.*	X[2]		
Viola nephrophylla Greene*		X[2]	X
Sedge sp.*		X	X
Other Grasses*			X

[1]Nomenclature as per United States Department of Agriculture 2010.
[2]Indicates uncommon species.

Appendix 3-1. List of species found at the 15 cm and 40 cm depth treatments in the first year of growth at the reclamation site. * Represents species native to Canada (as per USDA 2010). Nomenclature as per United States Department of Agriculture 2010.

Species Name	15 cm Treatment	40 cm Treatment
Achillea sibirica Ledeb.*	X	X
Amelanchier alnifolia (Nutt.) Nutt. ex M. Roem.*	X	
Anemone parviflora Michx.*	X	
Aralia nudicaulis L.*	X	X
Bassia scoparia (L.) A.J. Scott	X	X
Brassica napus L.	X	X
Calamagrostis canadensis (Michx.) P. Beauv. var. *canadensis**	X	X
Canadanthus modestus (Lindl.) G.L. Nesom*	X	X
Capsella bursa-pastoris (L.) Medik.	X	X
Chamerion angustifolium (L.) Holub ssp. *angustifolium**	X	X
Chamerion latifolium (L.) Holub*	X	X
Chenopodium album L.	X	X
Chenopodium capitatum (L.) Asch.*	X	X
Cirsium arvense (L.) Scop.	X	X
Collomia linearis Nutt.*	X	X
Corydalis aurea Willd.*	X	X
Crepis tectorum L.	X	X
Elymus repens (L.) Gould	X	X
Equisetum arvense L.*		X
Equisetum scirpoides Michx.*	X	X
Erysimum cheiranthoides L.	X	X
Eurybia conspicua (Lindl.) G.L. Nesom*	X	X
Eurybia sibirica (L.) G.L. Nesom*	X	
Fragaria vesca L.*	X	X
Galeopsis tetrahit L.	X	X
Galium boreale L.*	X	X
Galium triflorum Michx.*	X	X
Geranium bicknellii Britton*	X	X
Geum aleppicum Jacq.*	X	X
Heracleum maximum Bartram*	X	
Hieracium umbellatum L.*		X
Lathyrus ochroleucus Hook.*	X	X
Lonicera involucrata (Richardson) Banks ex Spreng.*	X	
Lonicera tatarica L.	X	X
Maianthemum canadense Desf.*	X	
Maianthemum stellatum (L.) Link*	X	
Melilotus officinalis (L.) Lam.	X	X
Mentha arvensis L.*	X	X
Mertensia longiflora Greene*	X	X
Mertensia paniculata (Aiton) G. Don. var. *paniculata**	X	X

Species Name	15 cm Treatment	40 cm Treatment
Moehringia lateriflora (L.) Fenzl*	X	
Petasites frigidus (L.) Fr. var. *palmatus* (Aiton) Cronquis*	X	X
Plantago major L.		X
Polygonum arenastrum Jord. ex Boreau	X	
Polygonum convolvulus L.	X	X
Potentilla norvegica L.*	X	X
Prunus pensylvanica L.f.*	X	X
Prunus virginiana L.*		X
Ranunculus cardiophyllus Hook.*	X	X
Ranunculus lapponicus L.*	X	
Ribes hudsonianum Richardson*	X	X
Ribes triste Pall.*	X	X
Rosa acicularis Lindl.*	X	X
Rubus idaeus L. ssp. *melanolasius* (Dieck) Focke*	X	X
Rubus pubescens Raf.*	X	X
*Salix petiolaris Sm.**	X	X
Silene latifolia Poir. ssp. *alba* (Mill.) Greuter & Burdet	X	X
Sinapis arvensis L. ssp. *arvensis*	X	
Sonchus oleraceus L.	X	X
Spergula arvensis L.	X	X
Stachys pilosa Nutt. var. *pilosa**	X	X
Stellaria media (L.) Vill.	X	
Symphoricarpos albus (L.) S.F. Blake*	X	X
Symphyotrichum laeve (L.) A. Löve & D. Löve var. *leave**	X	X
Taraxacum officinale F.H. Wigg.	X	X
Thlaspi arvense L.	X	X
Tiarella trifoliata L.*	X	
Trifolium pratense L.	X	
Trifolium repens L.	X	X
Tripleurospermum perforatum (Mérat) M. Lainz	X	
Vicia Americana Muhl. ex Willd.*	X	X
Sedge sp.*	X	X
Other Grasses*	X	X