University of Alberta

Assisted Natural Recovery Using a Forest Soil Propagule Bank
in the Athabasca Oil Sands

by

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ABSTRACT

Research objectives were to investigate the potential of two natural and locally available propagule sources, peat and LFH (forest floor), and two application depths (~10 and ~20 cm) to enhance native plant establishment and diversity. In a greenhouse component, seeds and vegetative propagules were enumerated from LFH and peat sources and placed LFH and peat. In a field component, plots were assessed for canopy cover by species, species density and various soil chemical and physical properties. LFH significantly enhanced plant community diversity, species richness, plant abundance and had more soil nutrients compared to treatments using peat as a surface soil. Application depth had little effect within peat treatments and the LFH thick application depth was more beneficial for plant establishment than the LFH thin application depth. LFH showed strong promise as a reclamation source of plant propagules.

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I. INTRODUCTION

1.0 BACKGROUND

Alberta's boreal forest is a valuable economic resource with increasing anthropogenic disturbances. Oil sands mining, oil and gas production, agriculture and forestry are some of the main contributors to disturbance within the boreal forest (Strong and Leggat 1992). In particular oil sands development creates a dramatic disturbance resulting in a completely denuded landscape. These lands require reclamation to plant communities comparable to those that naturally occur. Current and past reclamation practices to revegetate natural upland plant communities within the oil sands have had limited success due to a number of constraints: inadequate supply of native seed, competition from agronomic/aggressive native species and possibly dilution of the forest soil propagule bank through current soil salvaging practices.

Syncrude Canada Ltd. is currently the largest oil sands operator in the Athabasca Oil Sands Region (AOSR) of northeastern Alberta. Two major types of waste materials that require dry land reclamation as a result of the oil sands mining and extraction process are overburden materials and coarse tailing sands (Fung and Macyk 2000). Saline-sodic overburden materials make up the largest overburden piles at Syncrude Canada Ltd. Base Mine (Oil Sands Revegetation Reclamation Committee 1998). These dumps create many upland sites that are scheduled to be revegetated to native upland forest communities and any revegetation attempts have the same constraints mentioned previously, in addition to poor physical and chemical soil properties from the nature of the overburden materials.

Economical sources of native seed for revegetation of disturbed sites within the AOSR are not readily available. In 1999 and 2000 the Syncrude Environmental Affairs Department conducted an extensive review of native seed and plant suppliers in western Canada and concluded only a few commercial sources of plant material native to the boreal forest existed. The plant material available from suppliers was not considered a cost-effective option for reclamation on an operational scale (Lanoue and Qualizza 2001).

An alternative source of native seed, which is readily available and cost-effective is needed for very large disturbances.

The LFH layer of the organic horizon from the forest floor contains many viable seeds and vegetative propagules (Moore and Wein 1977; Archibold 1979; Granström 1986). Salvaged topsoil applied to reclaimed areas, as an amendment, can contribute to the long-term productivity of the site through additions of native propagules, organic matter and soil micro fauna (Leck et al. 1989). The use of specialized soil salvage and placement techniques for revegetation in the AOSR has the potential to establish diverse plant communities (Lanoue and Qualizza 2001). The use of donor soil seed banks as a revegetation technique has been successfully employed on other mine sites (Tacey and Glossop 1980; Grant et al. 1996; Rokich et al. 2000) and other land disturbances (Patzelt et al. 2001). However, there has been little scientific research conducted using boreal forest LFH for revegetation and there are few peer reviewed journals on the use of LFH as an amendment for revegetation in Canada. The majority of research assessing the use of donor soils for restoration used small scale plots; few attempts have used operational scale plots (Rockich et al. 2000; Zhang et al. 2001).

2.0 BOREAL FOREST ECOSYSTEM

The boreal forest is a large ecosystem from a global, national and provincial perspective. Globally the boreal forest encompasses approximately 11% of the earth's land surface, covering approximately 8% of the world's forested areas (Bonan and Shugart 1989; Alberta Environmental Protection 1998). This northern forest lies between latitudes 50 °N and 70 °N. From an ecosystem view, the boreal forest's northern boundary is the tree line and the southern boundary is the upper boundary of aspen parkland (Alberta Environmental Protection 1998). In Canada the boreal forest is the largest ecosystem, comprising 34 to 45% of the Canadian land base (McLaren 1990). The boreal forest in Alberta is known as the boreal forest natural region, it occurs north of the 55 ° latitude and covers approximately 53% of Alberta's land base (Alberta Environmental Protection 1998).

The boreal forest plays an important role in the cycling of the earth's carbon, water, nitrogen and oxygen. The boreal forest has a large influence on the seasonal and annual climatology of the Northern Hemisphere, creating warm surface air temperatures and increased atmospheric moisture levels all year long, and these effects extend from northern latitudes to the tropics (Alberta Environmental Protection 1998). On a more local scale the boreal forest plays an important role in regulating rainfall, temperature and weather conditions.

The boreal forest contains many utilitarian resources and may be considered a source of wealth rather than a green zone (Alberta Environmental Protection 1998). Some common human activities within the boreal forest natural region include agriculture, forestry, conventional oil and gas exploration and development, oil sands mining, peat mining, settlement and transportation and recreation. All of these activities result in some degree of disturbance, such as habitat destruction, reduced biodiversity, contamination and an increase in greenhouse gases (Alberta Environmental Protection 1998).

Natural disturbances, unlike anthropogenic disturbances, have been occurring frequently for thousands of years (Timoney 2003). MacDonald (1987) concluded that within the subalpine boreal forest, fires reached modern frequencies 6000 years BP (before present). Historically the average natural fire cycle ranged from < 50 to > 200 years on upland sites and poorly drained bogs, respectively (Bonan and Shugart 1989; Kenkal et al. 1997). The average fire interval for aspen and jack pine stands is 30 to 70 years and white spruce stands are longer, ranging from 72 to 142 years (Larsen and MacDonald 1998). Another common natural disturbance occurring in the boreal forest is insect outbreaks. Spruce budworm is a common pathogen that attacks spruce and fir forests (Bonan and Shugart 1989).

2.1 Boreal Forest Succession

Succession refers to changes in species composition and abundance during or following disturbance of a site (McCook 1994). Two primary types of succession exist, primary and secondary succession. Primary succession occurs on previously unvegetated terrain

(Finegan 1984). Examples of primary succession include glacial moraines, recent eolian deposits and areas disturbed by volcanic eruptions (Walker and de Moral 2003). Secondary succession occurs on disturbed areas that have remains of previous vegetation. Areas where primary succession takes place must rely on colonizing plants, whereas areas where secondary succession arises can also rely on existing viable seeds and vegetative plant parts.

Rowe (1961) was among the first scientists to apply successional theory to the boreal forest ecosystem. He distinguished the boreal forest as a disturbance driven system, in which forest fires were so common that the Clementsian view on succession was generally not applicable (Pickett et al. 1987; Bonan and Shugart 1989; Kenkal et al. 1997). Rowe also noted the importance of site history, edaphic conditions, species life-history characteristics and stochasticism in determining forest stand composition and stand dynamics. He considered succession as multi-directional trajectories, rather than a universal trajectory (Heinselman 1973; McCook 1994; Kenkal et al. 1997). Each site within the boreal forest is unique and there is an inherent difficulty in predicting the pattern of possible seral stages to a climax plant community.

In recent literature, it has become the consensus that multi-directional successional pathways in the boreal forest are more likely than a single successional pathway (Cook 1996; McCook 1994; Finegan 1984). Studies on the dynamics of forest structure and composition have shown both the initial floristic composition (Egler 1954) and the tolerance (Connell and Slayter 1977) models of succession were applicable to boreal forest ecosystems (Cogbill 1985; Galipeau et al. 1997). The initial floristic composition model views succession as proceeding from propagules, and the availability of propagules constrain reestablishment success following disturbance (Kenkel et al. 1997). Propagule availability is chiefly determined by random factors and site history, implying that succession is very heterogeneous (Kenkel et al. 1997). The tolerance pathway according to Connell and Slayter (1977), results initially with a species assemblage that is most efficient at exploiting limiting resources. Initially, early colonizers establish and eventually later successional species displace the early colonizers as the late successional species are more tolerant to the declining resource conditions (Walker and de Moral

2003). These two successional models do not provide a complete model of forest dynamics. Other succession models proposed include Connell and Slayter's additional facilitation and inhibition models and Grime's three basic plant-life history strategies: ruderals, stress tolerators and competitors (Kenkel 1997).

The typical successional pathway in a boreal forest stand is dependent on fire frequency, with frequent fires favoring resprouting, shade intolerant species and seed banking ephemerals (Kenkel et al. 1997). The ephemeral species could be *Epilobium* spp., *Populus* spp., *Betula* spp., or any other species that rapidly establishes in direct sunlight. The death of some of these species creates openings in the community. Openings in the community from the death of pioneer species releases site resources for the next seral species, such as *Picea* spp. and *Abies* spp., which are shade tolerant (Little 2001). Frequent disturbances created by wildfires, insect outbreaks and tree throw often keep boreal forest sites in early successional stages.

2.2 Disturbance

Disturbances are events discrete in time and space that alter the structure of populations, communities and ecosystems (Walker and del Moral 2003). Disturbances affect the abundance of populations and species within a plant community. Disturbance also has an important influence on ecosystem-level processes such as biomass accumulation, energetics, primary/secondary production and nutrient cycling (Sousa 1984). A disturbance may cause a net increase in soil nitrogen for available early colonizers that arrive in open spaces. The impacts disturbance have on populations, communities and ecosystems is related to the frequency, size and intensity of the disturbance (Oliver 1981). An understanding of disturbance frequency, size and intensity is critical in understanding successional pathways after a disturbance.

The size of a disturbance is the mean area disturbed. Disturbance size can have a large impact on the initial composition of the regenerating plant community; it affects the physical environment and arrival/survival of propagules (Turner et al. 1998). The size of a disturbance is closely related to edge effects. Centers of large patches will likely

experience different physical conditions than small patches or disturbances near intact vegetation. Larger gaps can create higher wind speeds, greater temperatures, lower humidity and reduced soil moisture (Denslow 1987). Small gaps disturbed are more likely to be provided with more propagules versus large areas because the density of propagule inputs decreases with increasing distance (McClanahan 1986). Centers of large disturbances are more likely to favor wind dispersed ruderal plants. Late successional species are less readily dispersed, thus succession may be slow near the center of the disturbance due to high competition for resources from these early arrivals.

The intensity of the disturbance is the physical energy of a disturbance event (Turner et al. 1998). Greater intensity disturbances create more severe damage to biota; the more intense a disturbance the greater the chance primary successional conditions may be created. The intensity of a disturbance can affect both biotic and abotic components of an ecosystem. High winds may cause many tree throws creating areas completely absent of organic matter. Intense forest fires may consume the litter layer leaving behind few biotic residuals to reestablish.

Frequency of disturbance is the average number of events occurring at an average period of time at a given location. In the absence of disturbance plant communities may develop into a climax plant community; too frequent disturbances may exhaust all biotic residuals for reestablishment creating conditions more favorable for wind dispersed ruderals.

3.0 SOIL SEED BANKS AND VEGETATIVE PROPAGULES

3.1 Seed Bank Classification

Seed, spores and plant vegetative parts on and under the soil surface are collectively known as the soil propagule bank. Understanding the basic components in their classification, dynamics, dispersal and regeneration mechanisms are critical components in understanding factors that limit their success in reestablishment after a disturbance.

Classification of seed banks is an important tool for understanding species and their environmental relationships (Olmsted and Curtis 1947; Thompson and Grime 1979;

Roberts 1981). Determining future vegetation after natural or anthropogenic caused disturbance from the soil seed bank can play a critical role in the success of any restoration project (Roberts 1981). The regeneration of a species after disturbance may be influenced by its persistence in the soil seed bank. If a species loses its viability in a seed bank it must rely on some other type of dispersal vector (e.g. wind, water, animals or humans) (De Villers et al. 2002). Knowledge of what types of seed banks are present prior to disturbance can help predict which species will establish after disturbance and which species need to be reintroduced.

Thompson and Grime (1979) classify seed banks into four types: two transient (types I and II) and two persistent (types III and IV). Transient seed banks are those with seeds that remain viable for less than one year, whereas persistent seed banks are those with seeds that remain viable for more than one year. Transient seed banks are not usually buried in the soil and are adapted to exploit the gaps created by seasonally predictable disturbances. Persistent seed banks, however, are found in the soil and can potentially regenerate in circumstances where disturbance of the vegetation is spatially and/or temporally unpredictable (Hills and Morris 1992).

Transient seed banks include both perennial and annual plants that usually have larger seeds, which may contain specialized dispersal mechanisms (Harper 1977). These seeds have hooks, awns, spines or other projections on the seed coat that enable them to disperse readily by wind or other mechanisms (Thompson and Grime 1979; De Villiers et al. 2002). Types I and II seed banks differ such that type I are present during summer and seeds germinate in autumn; type II are present in winter and seeds undergo a chilling requirement and germinate the following spring (Thompson and Grime 1979). Plants in type I seed banks are represented by grasses of dry or disturbed areas and herbs of northern regions represent type II seed banks.

Persistent seed banks include annual and perennial plants with small, lightweight seeds that usually lack specialized dispersal mechanisms (Harper 1977). The differences between types III and IV persistent seed banks are attributed to differences in timing of germination after dispersal. A large proportion of seeds in type III seed banks germinate

following dispersal leaving a small fraction buried in the soil. Grime (1981) further subdivided type III seed banks into two categories; type IIIa and type IIIb. Seeds in type IIIa germinate in autumn, unless they become buried in soil. The formation of a small seed bank is created from the small fraction of seeds that are deeply buried, which inhibits germination due to a lack of light. Type IIIb seeds germinate in spring. Seeds in type IIIb become buried during summer dormancy breaking period and their light requirement for germination prevents germination in autumn. In type IV seed banks few seeds germinate before they are buried in the soil, creating a large reserve of viable ungerminated seeds in the soil (Bakker et al. 1996).

3.2 Seed Bank Dynamics

Seed banks play an important role in plant population dynamics (Hills and Morris 1992). Soil seed banks are important for the regeneration of new populations (Leck et al. 1989). The characteristics, longevity and abundance of seeds present in the soil are determined by the relationship between seed inputs and outputs (Baskin and Baskin 1998). Seed inputs or seed rain is a function of plant density and per capita seed release (Leck et al. 1989). Outputs from the seed bank include losses to parasitism, predation, death and germination (Hills and Morris 1992). The dynamics of the seed bank are dependent on numerous factors, including seed dispersal (annual seed fall), seed sources (species and abundance), seed predation, seed decay, soil type and soil conditions (Hills and Morris 1992). The type of seed bank can have a large impact on the likelihood of one of these factors occurring. For example, seed predation rates are related to seed size. Transient seed banks are more susceptible to predation due to their large seed size, whereas persistent seed banks remain protected from above ground predators due to their small seeds falling down the soil profile (Hulme 1998).

3.3 Dormancy and Germination

Dormancy refers to a state in which seeds that will not germinate under any set of normal environmental conditions (Leck et al. 1989). Seed dormancy is an important process in seed bank dynamics, influencing whether a seed will become an input or output.

Dormancy can be dependent on fluctuations in light, temperature, air and moisture, which are also dependent on soil type, seed burial depth and environmental conditions (Baskin and Baskin 1998). Researchers suggest that dormancy might be induced when light and temperature conditions are low, which commonly occurs with deeply buried seeds (Thompson and Grime 1983; Leck et al. 1989; Clarke et al. 2000).

Baskin and Baskin (1998) divide seed dormancy at maturity into five general types: physiological, physical, combinational, morphological and morphophysiological. These are distinguished on the basis of physiological inhibiting mechanism (PIM) of germination (physiological) and resistance of seed coat to water penetration (physical), underdeveloped embryo (morphological). Leck et al. (1989) conducted a literature review and concluded that most species in the seed bank have physiological dormancy, while the other dormancy types follow in descending order of importance. Seeds with physiological dormancy undergo several changes in dormancy state: dormant, conditionally dormant and nondormant. While dormant seeds do not germinate under any set of environmental conditions, conditional dormant seeds will germinate under a limited range of environmental conditions, and nondormant seeds will germinate under any set of environmental conditions (Baskin and Baskin 1998).

Germination is the continuation of growth by the embryonic plant that has remained dormant in the seed (Hills and Morris 1992). Seeds can germinate both in the soil and on the soil surface. There is an inverse relationship between successful germination and seed burial depth because of an increase in induced dormancy with increasing burial depth (Baskin and Baskin 1998). Soil disturbances such as tillage or soil macrofauna activity can bring seeds to the surface and are exposed to more favorable environmental conditions for germination (Baskin and Baskin 1998). Germination requirements of seeds in soil are species dependent, each having its own requirements for breaking dormancy.

To germinate, a seed must remain in a particular microlocation long enough to imbide moisture. Dispersal and secondary movements of seeds onto microsites are important determinants of seed germination (Chambers and MacMahon 1994). If a seed moves too frequently it cannot continuously imbibe water and germinate (Johnson and Fryer 1992).

The probability of a seed finding a 'safe site' is species dependent and largely influenced by soil texture, soil structure and surface roughness.

Chambers et al. (1991) found in fine textured soils, smaller seeds remained trapped and reached greater depths compared to larger seeds. In coarser textured soils, both small and large seeds were trapped, but smaller seeds reached greater depths. In high clay content soils, seed with hygroscopic awns are favored and in soils with high sand content favor awnless species are favored (Chambers and MacMahon 1994). Johnson and Fryer (1992) conducted a study on the effects of surface roughness on seed germination and concluded that rougher soils trapped more seed, resulting in a higher proportion of seed germinating than in smoother soils. Increases in soil bulk density had a negative effect on seed incorporation and seedling emergence. Seedling entrapment and emergence was highest in soil cracks (Chambers and MacMahon 1994). For most seeds, germination occurs near the upper 2 cm of the soil surface, larger seeds are able to germinate at greater depths (Grant et al. 1996; Rokich et al. 2000). Light availability and limited carbohydrate reserves limited how deep a seed may germinate and establish.

3.4 Distribution of Buried Seeds In Forest Soils

Seed bank studies conducted in forest soil found seed viability to decrease with increasing burial depth (Moore and Wein 1977; Granström 1986; Hills and Stevens 1992). Kramer and Johnson (1987) reported that most viable seed (67%) occurs in the top 5 cm of the soil surface, while the remainder is present in the 5 to 10 cm mineral layer. Moore and Wein (1977) found that the highest percentage of seedlings emerged from the 0 to 2 cm layer of organic soil in all five of their study sites. They found more seedlings emerging from the upper layers of mineral soil than from the lower layers of mineral soil. The age of a forest determines the abundance of the soil seed bank. Total seedling emergence was highest in deciduous dominated stands (clear cut *Betula papyrifera* Marsh. (white birch) and *Fagus grandifolia* Ehrh. (American beech) sites) and decreased in conifer dominated stands (*Picea mariana* (P.) Mill. (black spruce) and *Larix laricina* (Du Roi) K. Koch (tamarack) sites) (Hills and Morris 1992).

3.5 Vegetative Propagules In Forest Soils

Natural regeneration in forests is not solely dependent on the seed bank. Beneath the forest floor many viable vegetative propagules exist that help maintain a plant community after natural and anthropogenic disturbances. Vegetative propagules regenerate asexually and contain axillary and adventitious buds capable of producing new stems/branches under variable environments (Anderson et al. 2001). Plant parts able to reproduce asexually include stems, rhizomes, tubers, bulbs, stolons, suckers, creeping roots and branches. Information about the mechanisms of regeneration by vegetative propagules in the forest is limited and the majority of study objectives have been to develop management plans that control or enhance the production of a particular species (Lieffers et al. 1996; Landhäusser and Lieffers 1997; Greene et al. 1999; Frey et al. 2003).

Clones from rhizomatous species have the potential to spread throughout the environment if activities that cut rhizomes and distribute them to new areas are implemented (Macdonald and Lieffers 1993). Segmentation of rhizomes activates many of the dormant buds along the rhizome resulting in the regeneration of newly formed sprouts (Powelson and Lieffers 1991). Sprouting in most herbaceous plants and shrubs is most vigorous when the total nonstructural carbohydrate (TNC) reserves are at their highest levels (Landhäusser and Lieffers 1997; Macdonald and Lieffers 1993). Landhäusser and Lieffers (1997) conducted a study on four boreal forest shrubs (*Corylus cornuta* Marsh. (beaked hazelnut), *Cornus stolonifera* Michx. (red-oiser dogwood), *Rosa acicularis* Lindl. (prickly rose) and *Viburnum edule* Michx. (low-bush cranberry) and found TNC reserves were highest in the later part of the growing season (August and September). Smaller segments (10 to 15 cm) of all the shrubs were as likely to produce an individual plant as the larger segments (> 15 cm). Powelson and Lieffers (1991) conducted a study on *Calamagrostis canadensis* (Michx) Beauv. (marsh reed grass) and found TNC gradually increased with increasing distance from the parental base and shorter segments resulted in greater total coverage compared to longer segments. Seasonal changes in carbohydrate reserves and the extent of disturbance to the roots system have a large impact on the survival of herbaceous and shrub species. Generally, disturbances in late

summer or early fall creating small root fragments (species dependent) will be as successful is establishment than disturbances created in spring with larger root fragments.

Greene et al. (1999) conducted a review on the regeneration dynamics of North American boreal trees species, and concluded only three tree species (*Populus tremuloides* Michx. (trembling aspen), *Populus balsamifera* L. (black poplar) and *Betula papyrifera*) could reproduce asexually from buds near the root collar. *Picea mariana* (P.) Mill. and *Juniperous* sp. can frequently layer in older stands. *Picea glauca* (Moench) Voss (white spruce), *Larix laricina* and *Abies balsamea* (L.) Mill. (balsam fir) will layer occasionally. Tree or meristem condition, microenvironment, associated plants, soil conditions, herbivory and type and intensity of disturbance affect regeneration from asexual reproduction. Regeneration success in tree species, such as sucker growth in *Populus tremuloides*, is strongly correlated with total TNC of roots (Frey et al. 2003). Length of root segmentation and timing of segmentation are known to significantly alter the TNC reserves in *Populus tremuloides*. Sucker growth is more limited on small segments because of the limited availability of TNC reserves (Frey et al. 2003) and TNC reserves in roots are significantly higher in fall than in spring and summer (Landhäusser and Lieffers 2002). From a management perspective, segmenting *Populus tremuloides* roots in fall often results in taller suckers with more leaf biomass than if cut in spring (Landhäusser and Lieffers 2002).

Strong and La Roi (1983) found that most roots of boreal trees (50%) are confined to the upper 15 cm of the soil profile and soil texture to a large extent determines the maximum rooting depth. They found that maximum rooting depth for boreal trees was greatest on sandy substrates and lowest on organic deposits. A literature review conducted by Frey et al. (2003) on sucker regeneration of *Populus tremuloides* indicated the majority of the smaller lateral roots were dispersed at depths of 5 to 20 cm. Jackson et al. (1996) composed a detailed literature review on root distributions for all terrestrial biomes and concluded grass species had 44% of their roots confined in the upper 10 cm while shrubs had only 21% in the same depth increment.

The distribution of roots will affect vegetative propagule establishment as it relates to the environment surrounding the vegetative propagule and regulates its susceptibility to disturbance (Frey et al. 2003). Deep buried roots are less likely to establish than shallow buried roots because of cooler temperatures, lack of light and limited amounts of stored carbohydrates (Frey et al. 2003). The success of a buried propagule emerging from deep burial is dependent on size of segments buried from individual species. Harris and Davy (1986) reported longer *Elymus farctus* (Viv.) segments could emerge from greater depths due to an increase in usable resources.

Disturbances can increase or reduce root survival by altering above and below ground temperatures, light availability, organic matter content, soil physical and chemical properties, moisture conditions and plant competition near the propagule (Greene et al. 1999). The type of disturbance and its intensity influences microclimate conditions that surround the root, thus affecting root survival. Generally, greater soil temperatures, increased light availability, lower bulk densities and a sufficient supply of nutrients and soil moisture enhanced plant establishment from roots. Extreme levels in any one of these environmental conditions can negatively affect plant emergence. Landhäusser et al. (1996) showed that high bulk densities reduced the growth of *Cornus canadensis* L. (bunch berry). Disturbance from machinery in thawed, wet conditions can increase soil bulk density, which can limit root growth of many tree species (Frey et al. 2003). When disturbances bring roots to the surface, exposure to warm dry wind and extreme temperatures can result in the death of viable roots (Frey et al. 2003). Disturbances created from topsoil stripping may result in variable survival rates of propagules because of the heterogeneous changes in microenvironments and redistribution of propagules throughout the soil profile.

3.6 Trembling Aspen-White Spruce LFH

Aspen-White Spruce stands typically occur on moderately drained sandy loams and finer-textured soils of moderate nutrient status (Strong and Leggat 1992). The organic layer in these stands is also known as the LFH layer and is developed primarily from leaves, twigs and woody materials, with a minor component of mosses (Agriculture Canada

Expert Committee on Soil Survey 1987). These early to mid successional sites contain shade-intolerant species that often contribute to a large seed bank. As the site ages white spruce begins to dominate resulting in fewer seed inputs (Moore and Wein 1977). Poplar and mixed-wood stands can contain 1,273 to 2,157 viable seeds m^{-2} (Hills and Morris 1992). Qi and Scarratt (1998) reported 9,690 seeds m^{-2} in a clear cut boreal mixedwood forest. Archibold (1979) sampled the forest floor from seven mixed stands of trembling aspen, paper birch and white spruce and found a mean total of 426 ± 152 viable seeds m^{-2}.

3.7 Black Spruce Peatland

Black spruce peatlands typically occur on deep, moist peat organic substrates where oligotrophic and acidic conditions prevail (Kenkel et al. 1997). There is little information on the quantity of seeds in black spruce dominated sites. Moore and Wein (1977) found few viable seeds in bog environments. Several environmental constraints that may lead to such few viable propagules in bogs are: soil temperature, low pH, poor soil aeration and excess soil moisture (Hawkins et al. 1995). Moore and Wien (1977) sampled soil from a *Sphagnum* spp. dominated bog and a *Larix* sp. peatland to a depth of 10 cm; no seedlings emerged from the *Sphagnum* bog and only dicotyledonous seedlings (320 ± 100 m^{-2}) emerged from the *Larix* sp. peatland.

4.0 PLANT DISPERSAL

4.1 Seed Dispersal

Plants can either disperse from the mother plant through seeds and spores or vegetative expansion. The major differences are between perennial and annual life histories. Generally, most perennial plants contribute more energy to vegetative expansion, fewer seeds are dispersed and seeds are short lived. Most annual plants contribute more energy to seed dispersal, more seed is produced and seeds are long lived (Chambers and MacMahon 1994).

Plant species that rely on seed production for survival must disperse their seeds away from the mother plant (Grime 2001). There have been numerous studies on abiotic factors influencing seed dispersal with wind being the major abiotic factor studied (Chambers and MacMahon 1994). The relationship between dispersed seeds and distance from source will vary depending upon such factors as height of release, wind speed, wind turbulence, speed of descent and specific morphological adaptations for dispersal (Augspurger and Franson 1987). Generally, with higher wind speeds and higher points of seed release lighter seeds will disperse the farthest (Auguspurger and Franson 1987; Okubo and Levin 1989). Most plant seeds move short distances from the parent plant with the exception of a few tree species (Sheldon and Burrows 1973). The resulting patterns of seed deposition are usually skewed, with a high proportion of seeds dispersing a short distance from the plant and then an exponential decrease (Okubo and Levin 1989; Bullock and Clarke 2000). Bullock and Clarke (2000) examined dispersal distance in relation to wind speed and direction for two dwarf shrubs (*Calluna vulgaris* (L.) Hull. (heather) and *Erica cinera* L. (bell heather); both plants dispersed the majority of their seeds within 2 m of the parent plant. Greater distances up to 80 m were recorded in the direction of prevailing winds and higher wind speeds. Seed dispersal distance is largely affected by seed morphology. Seeds bearing wings, pappus and plumose often disperse farther distances than seeds not bearing these appendages (Matlock 1987). Tree species with plumose bearing seeds, such as *Populus* spp. and *Salix* spp., can disperse their seeds several kilometers (Hills and Morris 1992). Tree seeds having appendages enhancing dispersal are able to disperse farther than herbaceous species with similar appendages because trees have a higher point of release.

Much attention has been devoted to biotic dispersal and several reviews discuss the influence of animals on seed dispersal (Chambers and MacMahon 1994). Biotic dispersal is described by the method of seed acquisition and dispersal by the animal (Chambers and MacMahon 1994). Seed is either transported passively or actively. Passive transportation occurs when seeds are accidentally transported on body surfaces (external) or consumed with other foods (internal). Active transportation occurs when animals select seeds and transport the seed to another location (Chambers and MacMahon 1994). Many seeds have

adhesive properties such as hooks or barbs for passive animal dispersal, which may result in longer dispersal than active dispersal by animals or wind dispersal (Chambers and MacMahon 1994). With passive external dispersal mammals walk through vegetation and seeds with adhesive properties attach to the fur (Fenner 2000). The distribution pattern of seeds for passive external dispersal is dependent on the nature of the adhesive property/hair interaction. The length of time a seed remains attached to the animal is dependent on individual animal behavior (Fenner 2000).

Active dispersal has been related to seed/fruit color and smell and the majority of active seed dispersal has been associated with birds. Some plants have adapted strategies to design fruit production, presentation and nutritional rewards to attract the greatest number and variety of dispersers as possible (Fenner 2000). Stiles (1982) hypothesized some species change leaf color early to provide a long distance signal for frugivores. Mammals that do not have good vision, or nocturnal species, must rely on their sense of smell. Other plants have appendages that attract animals and insects. Species such as ants are attracted to seeds with oil rich elaiosomes (appendages of various shapes). The fruit is not the only portion of the plant that attracts animals to enhance seed dispersal, Janzen (1984) hypothesized herbaceous vegetation can act as an attractant for large herbivore dispersal of seeds. Quinn et al. (1994) supported the foliage of the fruit hypothesis, showing the high quality of forage from two grass species increased germination and dispersal after passage through domestic cattle's digestive tract.

There is little information relating seed dispersal to dispersal vectors in the boreal forest. The majority of the work conducted in the boreal forest focuses on wind dispersed tree seeds (Farmer 1997). In general the dispersal distance for boreal trees increases with species that have appendages adapted to wind dispersal, assuming no dispersal from birds or mammals. Dispersal distances for some common boreal trees follow the following sequence: *Populus* spp. > *Salix* spp. > *Betula* spp. > *Abies* spp. > *Picea* spp. (Hills and Morris 1992). There is little information on distances and modes of dispersal for understory species in the boreal forest, however, some other forested areas contain some information. Matlack (1994) found plant species migration in several mixed-hardwood forests were significantly affected by ingestion, adhesion, wind dispersal and ants. He

suggested the following generalized ranks of migration rates: ingested > adhesive > wind > ants > none.

The majority of the information describing humans as dispersal pathways focuses on weedy species. Hodgkinson and Thompson (1997) reviewed the role of humans as dispersal vectors. They briefly describe humans as dispersal vectors through two broad categories, soil movement and phytoculture. Within the soil there are viable seed and vegetative propagules, and when the soil is dispersed the associated propagules are also dispersed. Soil is dispersed in mud on animal hooves, on birds, on human feet and bodies, on animal fleeces, on vehicles and on agricultural and industrial machinery and their associated equipment. There is little information concerning plant dispersal from motor vehicles, however, most plants are dispersed through seed attachment from roadsides where the mud attaches to the undersides and wheels of the vehicles (Hodkinson and Thompson 1997). The roads in which vehicles travel provide excellent corridors for plant dispersal. Vehicles aid plant dispersal along the road but also carry propagules between sites making the combination of roads and vehicles an effective dispersal vector (Belsky 1987). The other common dispersal vector, phytoculture, includes transport of seed through impurities in commercial seed and deliberately sown seeds by humans for use in silviculture, agriculture or horticulture (Hodkinson and Thompson 1997).

4.2 Vegetative Expansion

Plants that allocate their energy to vegetative expansion disperse from the mother plant through lateral movements on or within the soil surface. Vegetative expansion is frequent in unproductive habitats and on forested areas where small local disturbances occur (Grime 2001). Vegetative expansion has many environmental controls including soil bulk density, soil moisture, soil nutrient availability, soil pH, soil temperature, soil texture and climatic conditions regulating growth of the mother plant, that influence how far their vegetative parts can move onto adjacent areas (Landhäusser and Lieffers 1999; Frey et al. 2003). Increases in soil bulk density and low soil moisture can slow the lateral expansion of certain grass species (Landhäusser and Lieffers (1999). Macdonald and Lieffers (1993) found rhizome length of *Calamagrostis canadensis* to decrease with decreasing soil

temperatures and increases in plant competition. The distance roots move laterally is species dependent. *Epilobium angustifolium* L. (fireweed) roots can move 0.25 m laterally in two years from establishment and 2 to 3 year old established plants had lateral root distances up to 1.2 m (Antos and Halpren 1997). *Rosa acicularis* and *Ledum groenlandicum* Oeder. (labrador tea) can cover areas of 10 to 25 m^{-2} (Calmes and Zasada 1982). Dispersal distance of poplar suckers have been observed up to 21 m from the nearest bole with an average distance of 5 m from the nearest bole (Greene et al. 1999).

5.0 RECLAMATION

5.1 Donor Soils

The use of donor soil from a nearby site with the appropriate vegetation is potentially one of the easiest and least expensive ways to establish native vegetation (Leck et al. 1989). The majority of research using donor soils for revegetation has been conducted on mines. Large disturbances created from mining operations cannot rely on economical or readily available sources of native seed for revegeation; therefore they must utilize every resource that is available. Most of the research conducted using the soil seed and propagule bank in forests has been conducted in subtropical, temperate, arid and bog environments (Tacey and Glossop 1980; Farmer et al. 1982; Skousen et al. 1990; Koch et al. 1996; Standen and Owen 1999; Rokich et al. 2000; Zhang et al. 2001). All studies concluded that the use of the soil seed and propagule bank enhanced native vegetation establishment.

Many scientific studies have evaluated the propagule bank's role in natural recovery from boreal forest plant communities after fire or logging disturbances (Archibold 1979; Paré et al. 1993; Bock and Van Rees 2002), but few studies have focused on the use of boreal forest LFH as a donor soil for revegetating disturbances created through surface mining. Smith (1997) studied the effects of using donor soils from a sandy soil to create a diverse plant community on a coal mine spoil in the rocky mountains. The addition of the litter layer, topsoil and upper subsoil mixed together resulted in the fastest rate of vegetation establishment and highest plant cover versus using no donor soil.

Effective use of the topsoil seed bank for natural regeneration depends on salvage depth and depth of respread topsoil (Rokich et al. 2000). On a small scale field trial Tacey and Glossop (1980) found double stripping the top 5 cm of topsoil from the donor site significantly increased plant and litter cover compared to the stripping method that incorporated the entire 40 cm topsoil profile in the Jarrah forest. The shallow stripping treatment was more comparable in species richness, diversity and equitability to the natural Jarrah forest. A separate greenhouse experiment conducted by Tacey and Glossop (1980) reported that 93% of the seedlings emerged from seeds in the upper 2 cm of the top 10 cm of topsoil from the Jarrah forest. Grant et al. (1996) also conducted a greenhouse study using stockpiled topsoil from the Jarrah forest and concluded that the majority of the 12 species planted emerged from a planting depth of between 0 and 2 cm and seedling emergence was significantly reduced below 5 cm. Concluding remarks from the green house study were that topsoil should not be salvaged greater than 15 cm and should be spread at a minimum depth of 5 cm to utilize the soil seed bank most effectively.

Operationally current methods for optimizing the recovery of the top 5 cm or less from premined vegetation are difficult to implement on a large scale (Darryl Ramsaran , personal communication; Rokich et al. 2000; Leck et al. 1989). Problems associated with stripping forest soils at a constant shallow depth include variation in topography and soil type, roots, rocks and moisture conditions. Removal of the top 10 cm is desirable and practical using current soil stripping methods, as the number of seeds beyond 10 cm is negligible (Rokich et al. 2000). Rokich et al. (2000) conducted a larger field scale study to determine the effects of topsoil stripping depth using field scale equipment, on plant establishment. They concluded that the removal of 30 cm of topsoil decreased total species recruitment three times more than the removal of 10 cm of topsoil (81 seedlings 5 m^{-2} vs. 254 seedlings 5 m^{-2}).

Utilizing the majority of the seed bank also depends on topsoil replacement depth. Depth of buried seed affects the ability of the seed to emerge and establish (Section 2.2.4). A study conducted in the boreal forest by Qi and Scarratt (1998) found almost twice as many seedlings emerged from the organic layer in a germination test than the intact

organic and mineral layer. Grant et al. (1996) found most species did not emerge from depths greater than 5 cm and those that did emerge from depths greater than 5 cm were all heavy weighted seeds. Similarly, Rokich et al. (2000) demonstrated no significant difference in seedling recruitment between 10 cm and 30 cm topsoil application depths.

5.2 Syncrude Practices on Saline Sodic Overburden Piles

The initial stages of reclamation begin with material salvage. Salvaged materials include peat and non-saline/non-sodic overburden. The peat is salvaged and mixed with the underlying mineral material to create a peat-mineral mix. Over salvaging of the mineral material was approximately 40% of the peat depth, but recently is now about 25 to 30% (Yarmuch 2003). Secondary mineral materials are also salvaged. Secondary mineral materials are suitable upland soil or surficial geologic material salvaged to a depth no longer considered suitable for plant growth is salvaged (Yarmuch 2003). Secondary material is screened prior to salvaging for desirable hydrocarbon content, pH, SAR and clay content (Fung and Macyk 2000).

Once materials are salvaged, secondary mineral material is hauled to overburden piles and spread over the overburden to a depth of 80 cm. The following winter the peat-mineral mix is spread over the secondary mineral material at an average 20 cm depth. When the peat-mineral soil is thawed enough to be broken up, a dozer is used to break up the large peat chunks to help even out the application depth and fill in areas that do not contain peat. Often a tailings pipe is pulled behind the dozer to increase efficiency in spreading and create a smoother surface for further reclamation processes.

Revegetation of the overburden piles is initiated with the introduction of a cover crop of barley (*Hordeum vulgare* L.) for erosion control and nutrient retention within the rooting zone. The cover crop is fertilized to provide available nutrients for the barley (Lanoue 1999). The following growing season, tree and shrub seedlings are planted (Fung and Macyk 2000). Collection of all propagation materials must be from an 80 km radius (Fung and Macyk 2000). Additional sources of propagules establish on site through what is available in the soil propagule bank or invasion from the surrounding area. The

remaining native vegetation is established through natural recovery via viable soil propagules and dispersed seeds.

6.0 General Research Objectives and Thesis Overview

Alternative sources of native boreal propagules are necessary in the Athabasca oil sands region if reclamation objectives are to recreate diverse native boreal ecosystems on disturbed lands. This research studies the use of LFH to improve native boreal species establishment on an overburden pile at the Syncrude Base Mine. A comparison between LFH and peat-mineral mix at two different application depths, approximately 10 (thin) and 20 cm (thick), is evaluated.

In Chapter 2 the potential of LFH as a source of propagules for revegetation through natural recovery in the oil sands region from an aspen-white spruce stand developed on fine textured soils is assessed. A comparison of propagule densities is made between an LFH donor site and a Peat donor site prior to salvaging the organic layers. Propagules were identified to species where possible and species enumerated in a controlled growth chamber. Origin from plant vegetative parts or seeds/spores was recorded. A second growth chamber study was conducted to examine the soil propagule bank after donor soils were applied at the receiver site the following spring. The chapter concludes with future research recommendations for examining the propagule bank from donor sites developed on fine textured soils.

The third chapter covers a field experiment comparing LFH and peat-mineral mix donor soils and effects of their application depth on the natural recovery of plant species from the soil propagule bank and plant species occurring in the surrounding area. Soil analyses results from treatments are used to determine why plant establishment is greater in certain treatments and to determine any future research required to help improve the establishment of native species from the soil propagule bank. The last chapter discusses the overall findings of the research and future research necessary for improving plant establishment from the soil propagule bank from donor soils used in the oil sands region.

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II. POTENTIAL OF BOREAL FOREST SOIL AS A PROPAGULE BANK AND ITS APPLICATIONS IN THE OIL SANDS REGION

1.0 INTRODUCTION

Open pit mining of oil sands in the mixed wood boreal forest of north eastern Alberta, Canada (Athabasca Oil Sands Region) (AOSR) creates very large and intense disturbances with 315,000 ha having the potential for disturbance (Alberta Government 2005). The disturbances created through oil sands removal and processing include pits, overburden piles, tailings dykes and by products from the oil extraction procedures such as sulphur blocks and coke. Disturbances need to be reclaimed to diverse, self-sustaining boreal forest plant communities similar to those in the surrounding region as set out by provincial regulations and guidelines (Alberta Environmental Protection 1998; Oil Sands Revegetation Reclamation Committee 1998; Fung and Macyk 2000). Commercial supplies of native species seed are limited to a few species with the majority of species unavailable (Lanoue and Qualizza 2000). An alternative source of native propagules (seed, spores and plant vegetative parts) is available in a rich thin organic surface horizon, commonly known as the LFH layer, of upland forests.

The LFH horizon is a thin organic horizon composed of fresh intact, identifiable litter (L), fragmented and fermenting litter (F) and humus (H) with small amounts of moss (Agriculture Canada Expert Committee on Soil Survey 1987; Pare et al. 1993). Stripping a thin layer from the surface for large scale operations has been considered uneconomical in the past. However, current research has shown numerous propagules exist in this horizon and are available for revegetation after natural disturbances, such as fires and tree throw (Whittle et al. 1997; Qi and Scarratt 1998; Rydgren et al. 2004). The LFH layer as a donor soil could add many ecological benefits that far outweigh the cost of salvaging the thin layer through additions of upland species tolerant to drier conditions, a concentrated layer of propagules at the surface, organic matter, soil micro/macro fauna and soil nutrients (Leck et al. 1989; Huang and Schoenau 1996; Qi and Scarrett 1997).

Effective use of donor soils as a source of propagules for revegetation relies on application depth (Rokich et al. 2000). The few studies that assessed application depth of

topsoil on mine sites all concluded that spreading at thin depths, such as 10 cm, gives similar results in seedling density and species richness as spreading at thick depths, such as 30 cm (Tacey and Glossop 1980; Rokich et al. 2000; Zhang et al. 2001). Grant et al. (1996) researched seedling establishment from a Jarrah forest in Australia and found the majority of seeds emerged from the upper 2 cm of surface soil. They indicated spreading topsoil at depths less than 2 cm could maximize its use.

The use of donor soils as a propagule source for revegetation on mine sites is well documented in subtropical, temperate and arid regions, however its applicability in the boreal forest has not been well researched (Tacey and Glossop 1980; Iverson and Wali 1981; Grant et al. 1996; Holmes 2001; Zhang et al. 2001). Numerous studies exist on the abundance and composition of the soil seed bank in upland coniferous and deciduous forests. However there is a lack of research pertaining to peatlands and fewer studies have considered the vegetative bank (Moore and Wein 1977; Archibold 1979; Whittle et al. 1998; Lee 2004). There is a lack of information on the effects of application depth on the soil propagule bank from donor soils in the boreal forest. The majority of research plots are built under controlled conditions on a small scale to help increase replication and reduce environmental noise, however this is not representative of large mine scale reclamation.

2.0 OBJECTIVES

This research focuses on the soil propagule bank for vascular plants from peat and LFH, two common organic horizons found in the Athabasca Oil Sands Region. Characterizing the potential species pool contained within the soil propagule banks of these horizons will provide baseline data for future research and potentially lead to a new standard in selection of donor soils for revegetation in the AOSR. The experimental approach used plots large enough to determine responses using standard sized, field scale, operational equipment, making it more directly applicable to field scale reclamation.

The research objectives were to characterize the abundance, composition and diversity of the soil propagule bank prior to soil salvaging and after field scale application in two separate controlled growth chamber studies.

3.0 METHODS

3.1 Research Site Description

The research area is 40 km north of Fort McMurray, Alberta at the Syncrude Canada Ltd. Base Mine site, located within the central mixed-wood subregion of the boreal natural region. The region has a cool temperate climate with short cool summers and long cold winters (Strong and Leggat 1992). Mean annual temperature is 0.7 °C and average annual precipitation is 455.5 mm (Environment Canada 2003). January temperatures (average of –18.8 °C) are typically the lowest while July temperatures (average of 16.8 °C) are the highest (Environment Canada 2003). Annual precipitation as rain is approximately 342.2 mm with 155.8 cm from snow (Table 2.1).

Soils developed on these landforms consist mainly of Luvisols, Gleysols, Brunisols and organic soils (Agriculture Canada Expert on Soil Committee 1987). Upland areas contain soils mainly of the Luvisolic order, while low areas are dominated by organic soils and peaty Gleysolic soils (Yarmuch 2003). Vegetation is composed of a mix of coniferous and deciduous forests. Upland areas typically consist of deciduous forests of *Populus tremuloides* Michx. (trembling aspen) and *Populus balsamifera* L. (balsam poplar), mixed with *Picea glauca* Moench (white spruce). Lowland areas are represented by *Picea mariana* (Mill.) BSP (black spruce) and *Larix laricina* (Du Roi) K. Koch (tamarack) (Fung and Macyk 2000).

3.2 Donor and Receiver Site Descriptions

The donor sites at Syncrude Canada Ltd. were located adjacent to each other, bordering the oil sands extraction pit (Figure 2.1). The area had been cleared (salvaged timber) and drained in 2002 in preparation for mining (Darryl Ramsaran, Personal communication). The total area used for salvaging comprised approximately 9 ha of upland forest (LFH

donor site), lowland forest (Peat donor site) and a transitional zone. Estimates of the donor sites area and previous vegetation cover were made in fall 2003 when the propagule bank was sampled. Within the 9 ha area approximately 54% upland forest (LFH donor site), 29% lowland forest (Peat donor site) and 17% transitional. Prior to timber salvaging the LFH donor site would have been vegetated with trembling aspen with sparse amounts of white spruce. Before the peatland was drained and timber salvaged, the dominant plant cover at the peat donor site would have been from black spruce and ericaceous shrubs. The transitional plant community contained dominant species found in both upland and lowland plant communities

After harvesting and prior to salvaging materials the donor sites were divided into two distinct vegetation communities and soil types, peat and LFH, for salvaging. Just prior to salvaging, the peat donor site was dominated by *Salix* sp. (willows), *Ledum groenlandicum* Oeder (labrador tea), *Oxycoccus microcarpus* Turcz. (small bog cranberry), *Vaccinium vitis-idaea* L. (bog cranberry), *Carex* sp. (sedges) and *Calamagrostis canadensis* (Michx) Beauv. (marsh reed grass). The organic horizon was composed dominantly of peat (> 40 cm) and an underlying saturated mineral soil. The LFH donor site was dominated by *Populus tremuloides*, *Salix* sp., *Rosa acicularis* Lindl. (prickly rose), *Calamagrostis canadensis*, *Carex* sp., *Fragaria virginiana* Duchesne (wild strawberry), *Epilobium angustifolium* L. (fireweed), *Aster ciliolatus* Lindl. (Lindey's aster) and *Petasites palmatus* (Ait.) A. Gray (palmate-leaved colts foot). The soil had a distinct thin LFH layer (mean depth 7.5 cm) with underlying mineral soil consisting of eluviated A horizons , illuviated B horizons and gleyed A and B horizons. A transition zone existed containing a mix of dominant plant species found on both lowland and upland areas.

The receiver site is located on a saline-sodic overburden pile (W1) of Syncrude's Base Mine (Figure 2.1). Saline-sodic overburden materials associated with marine shales of the Clearwater Formation have electrical conductivities greater than 4 dS m^{-1} and a sodium adsorption ratios ranging from 18 to 37 (Fung and Macyk 2000). The research site is located on a southeast aspect, situated on the upper/mid slope of the overburden pile. Topography consists of three forward slopes (7 to 16%) and two benches (-2 to 4%)

(Figure 2.2). Length of slopes and benches vary within and between experimental units, with more variation within. The slope length ranges 18 to 47 m and the length of benches range from 20 to 45 m. The experimental location is representative of an oil sands overburden pile and was selected based on timing of operations and availability. The southeast aspect provided a large enough area to conduct the experiment, a moderate slope and is representative of the harshest climatic conditions in the area (warm and dry). Construction was completed in late February 2004 with a 90 cm layer of secondary mineral soil (mixture of nonsaline/nonsodic overburden) placed over the overburden.

3.3 Experimental Design, Treatments and Plot Establishment

The experiment was established in a complete randomized design with 4 treatments, a thick application depth (≈20 cm) of peat and LFH and a thin application depth (≈10 cm) of peat and LFH, replicated three times (Figure 2.3). Each treatment was 25 m wide running 150 m parallel to the slope for a total of 12 experimental units. The total size of the site is 300 m wide x 150 m long. Buffers between treatments were not implemented because of operational limitations due to the size of the equipment being used. The limited volumes of LFH and the size of the site allowed a maximum of three replicates. Treatments were large in size to incorporate true responses to the equipment that would be used in normal operations. Treatments were surrounded by peat-mineral mix.

The two donor soils were salvaged in November 2003. The entire peat layer (> 40 cm) of the peat donor soil and underlying mineral material was salvaged using D10 Caterpillar® bulldozers. The entire LFH layer of the LFH donor soil with approximately 5 to 20 cm of mineral material underlying the LFH layer was salvaged with the same equipment as the peat donor soil. The LFH and peat stockpiles were inspected in December 2003 to select the material to be used in the experiment. Some surface soil from the transition vegetation zone was mixed in with some peat and LFH salvage piles, approximately 5% of some of the piles.

Treatments were applied on February 28 and 29, 2004. Treatments were applied starting from the most westerly treatment and working east (Figure 2.3). Thick treatments

received 5 haul truckloads and thin treatments received 3 haul truckloads. Each load contained approximately 160 m^3 of material. Three loads were deemed the minimum-loading rate for thin treatments. Initially two loads were applied to a single treatment receiving a thin application depth to get an average application depth of 10 cm, however, more than a third of the area was left uncovered resulting in large bare areas that would not be representative of treatment effects. Average application depths were 21.3 cm for thick treatments and 12.8 cm for thin treatments, from here on application depths are referred to as thin and thick.

Treatment application was consistent for each application depth. A Hitachi E2576 hoe was used to load the propagule source material from the stockpile into Hitachi 4500 Euclid haul trucks which transported the material approximately 3 km to the research area. The haul trucks dumped the material beginning at the upper slope and finishing at the lower slope. Prior to spreading donor soil at the receiver site, a large grader formed a road for the haul trucks through the centre and lower portion of the entire experimental area in an east/west direction. The trail was 10 m in width; the middle trail was 105 m north of the southern boundary of the experimental site and the lower trail was 25 m north of the southern boundary of the experimental site. A D10 Caterpillar spread out the material as uniformly as possible for each treatment area from top to bottom in all treatments. Application depth was not uniform within each experimental unit. Limitations of even application depth include uneven surface topography of the secondary mineral soil and physical conditions of the donor soils being applied (e.g. frozen lumps of ice and clay).

During LFH application some experimental units received more transitional material than others. The farthest west thick LFH treatment received one load of transition material. The thick LFH treatment to the east received approximately less than 5% transition material mixed with LFH. Three loads were applied to the second treatment from the west. Spreading peat in winter resulted in large frozen peat lumps with bare ground in between the lumps. These lumps were spread in early June to fill in the bare areas and obtain the desired application depth throughout the replicates using a mid size dozer

pulling a 15 m wide pipe. Each experimental unit was spread with one pass down the slope and one pass up the slope.

3.3.1 Soil propagule bank sampling

From September 25 to 28, 2003 the vegetation and propagule bank were sampled along three 300 m long transects, located 75 m apart. Transects intersected both upland and lowland plant communities. Sampling occurred at 10 m intervals along each transect. A total of 30 and 56 samples were taken from the peat and LFH sites, respectively. The vegetation assessment was conducted using 0.1 m^2 quadrats and presence/absence of plant species established within the quadrat was recorded. Adjacent to the quadrat an approximately 10 cm x 10 cm area of surface organic horizon was sampled to a depth of 10 cm. A serrated knife was used to cut dimensions of the sample then it was lifted out and split in half as upper and lower strata. The samples were placed in plastic bags and stored in coolers for transport. Coarse organic debris was not excluded from samples at the beginning of the experiment because one objective was to determine the contribution of vegetative propagules in the soil propagule bank; these fragments contained smeared organic material that would possibly have contained germinants that needed to be accounted for in the study (Granström 1986).

The propagule bank of the donor soil at the receiver site was sampled immediately after the peat treatments were redistributed on June 8, 2004. Two transects were randomly placed within each treatment and samples were taken along each transect every 10 m using a 7.5 cm diameter by 7.5 cm depth core. Core size was selected based on a sampling area sufficient to include both seed and plant vegetative parts that would potentially emerge. The donor soils were too fragile for a knife to extract the sample therefore cores were used. A total of 28 samples per experimental unit (336 in total) were determined from the seed bank data collected from fall 2003.

3.4 Growth Chamber Procedure

Two growth chamber studies were used to estimate abundance and composition of the propagule bank, one with donor soils prior to salvaging and the other with applied donor

soils at the receiver site. The 10 x 10 cm samples taken at the donor sites were extracted with a 5 cm^2 diameter core for each stratum. Samples collected at the donor site were placed in 8 x 12 cm containers and samples collected at the receiver site were placed in 12.5 x 12.5 cm containers. All samples were spread to a depth of 2 cm in plastic containers lined with 1 cm of vermiculite. A total of 60 and 112 containers were used for peat and LFH donor sites, respectively. In the second growth chamber study, 336 containers were used.

Containers were kept in a growth chamber at the University of Alberta and watered every other day to keep samples moist. Environmental conditions in the growth chamber were selected to mimic growing conditions at Fort McMurray; 21 °C during the day for 16 hours and 15 °C at night for 8 hours. The studies were conducted for 7 months each to ensure no new seedlings emerged. Established species and their densities in each sample were recorded two weeks after the initial potting and at monthly intervals thereafter. Samples were remixed by hand after each enumeration period to promote emergence by bringing up buried seeds within the pots and reduce thickness of the moss layer to promote light penetration (Thompson et al. 1997).

Whether individual plants that emerged came from plant vegetative parts or from seeds/spores was determined by checking the root structure (presence of remnant vegetative parts) and presence of cotyledons (Lee 2004). If propagules could not be identified as coming from either seed or plant vegetative parts due to emergents dying before final identification or the fragile roots breaking upon extraction from pots they were called propagules of unkown origin. All plants were identified to species if possible at the end of each counting period and unidentified seedlings were left to grow to produce morphological structures to assist in identification. All seedlings were removed after identification and seedlings that could not be identified morphologically were removed and placed in separate pots for future identification. Some plants could not be identified because death between enumeration periods occurred for species that did not reveal any identification structure. Species nomenclature follows Moss (1993). Abundance was calculated as propagules per m^2 from sample areas used in each growth chamber

procedure. The abundances at each enumeration period were combined to give a total abundance.

3.5 Analyses

Prior to analysis of species abundance data, species were divided into 11 plant groups based on sum of all plants (total), morphology (grasses, sedges, rushes, woody plants, forbs and pteridophytes), life history strategy (perennial and annual/biennial) and origin (native to North America or introduced) (Table C.1). Unknown monocots and dicots were excluded from all plant groupings except total. Measures of diversity included species richness (R), species diversity (H'), evenness (E) and Sorenson's qualitative similarity index (S) to above ground vegetation and propagule bank at the donor sites. Species richness was calculated as total number of species in each donor site and each replicate at the receiver site. Species richness excluded unidentified individuals (e.g. *Salix* sp. and *Carex* sp.). Diversity was calculated using the Shannon-Wiener index and evenness was calculated using the formula $E = H'/\log_{10}R$ (Magurran, 1988). Sorenson's similarity index was calculated using the formula $S = 2 \times N/(2 \times N + R1 + R2)$, where N = number species found in both sites and R1 and R2 is species richness in donor site and receiver site, respectively. Plant's that could not be identified to species (unknown grasses, herbs, and woody plants, *Carex* sp. and *Salix* sp.) were excluded in the diversity measures.

The Mann-Whitney test was used to compare differences in abundance on plant groupings between the peat and LFH donor site for the 0 to 10 cm depth interval (Zar 1999). The Wilcoxon paired-sample test was conducted on the plant groupings within each donor soil for differences in soil propagule abundance between the lower and upper stratums. A p-value of 0.05 was used to determine significant differences. Diversity measures are reported from a total of all the sample points.

Two-way analysis of variance was used to determine significant differences among treatments for the response variables at the receiver site (Zar 1999). Data from the subsamples within each experimental unit were pooled together to give one value per plant group in each experimental unit. Untransformed data was used in the analysis.

Shapiro-Wilk's test for normality and Levene's test for equal variances prior to analysis were conducted, with emphases placed on homogeneity of variance. Most variables met homogeneity of variance. Those that did not were transformed using the square root or log transformation. Transformed data were compared with raw data and in most cases transformed data did not alter interpretation of results or results from transformed data made little sense to the raw data. Given the small sample size, tests for normality and homogeneity of variance are sceptical and presentation of both transformed and untransformed data would have complicated interpretation (Finney 1989). Thus all untransformed data were used in analyses. Analyses that had significant interaction effects were further analyzed using Tukeys post hoc test for significant differences between treatments (Zar 1999). A p value of 0.1 was used to determine significant effects. A p of 0.1 was used instead of 0.05 to increase power to offset effects from the small sample size.

4.0 RESULTS AND DISCUSSION

4.1 Soil Propagule Bank at Donor Sites

4.1.1 Abundance

Total propagule density for the LFH donor soil was 9,108 propagules m^{-2} (range 0 to 41,229), significantly higher than the peat donor soil with 3,614 propagules m^{-2} (range 0 to 11,198) (Tables 2.2 and A1). Native species comprised the majority of the propagule bank of both donor soils (Table 2.2). Perennials accounted for more than 80% of the total abundance at both donor sites. Dicotyledons were most abundant in peat donor soil (45%) and monocotyledons (50%) in LFH donor soil (Table B.1). The LFH donor site had significantly higher densities for the majority of the plant groupings except pteridophytes, woody species and introduced species (Table A.1). Thus even a thin LFH layer from upland forests can be important for reclamation in the oil sands region, as it contains many propagules that can potentially increase revegetation success.

Propagule bank density in the upper 10 cm of the peat donor site was higher than that found in most of the literature. Moore and Wien (1977) found no emergents from a 0 to

10 cm depth of peat in a bog and only 320 ± 100 m^{-2} dicotyledonous seedlings emerged from a *Larix* bog; however they just studied seeds. Only one study in Canada had comparable results to the LFH donor site, others were much lower. Although total propagule density included seeds, spores of pteridophytes and plant vegetative parts, the total seed abundance was still higher than the majority of other studies. Qi and Scarratt (1998) reported 9,690 seeds m^{-2} in a clear cut boreal mixedwood forest, Archibold (1979) recorded 420 seeds m^{-2} in a boreal mixed wood forest and Fyles (1989) estimated 505 to 2,650 seeds m^{-2} in boreal coniferous forest.

Past disturbance history (clear cutting and draining), variations in year-to-year seed production (Qi and Scarratt 1998), extended period of time in the growth chamber and near proximity to the upland site may explain the high abundance of propagules in the peat donor site. Harvesting and drainage of the peat donor site may have allowed for species such as *Agrostis scabra* and *Carex* sp. to establish in high densities compared to an undisturbed peatland, thus creating opportunities to build up a greater propagule bank. Qi and Scarratt (1998) conducted their greenhouse study for approximately four months and total seed densities were higher than in this study. Vegetation type in combination with soil type play an important role in propagule bank abundance and this study supports results from Moore and Wein (1977) where higher propagule density was found in upland soils of deciduous forests than in some organic soils of peatlands.

The majority of plant groups from both donor sites had higher densities in the upper stratum compared to the lower stratum, however few were non-significant (Tables 2.2 and A.2). In the literature propagule abundance often decrease with increasing depth, regardless of propagule type (Leck et al. 1989; Jackson et al. 1996). However, Qi and Scarratt (1998) found lower seed abundances in the upper surface layer, possibly due to low seed inputs from a sparse understory. The extensive root system of *Equisetum arvense* L. (field horsetail) and the persistent nature of *Potentilla norvegica* L. (rough cinquefoil) seeds would explain why plant groups containing these species were more abundant in lower stratums than other plant groups. Salvaging either LFH or peat donor soil too deep could thus reduce propagule abundance at the receiver site through dilution

with lower soil layers that do not contain abundant propagules (Tacey and Glossop 1980; Rockich et al. 2000).

Seeds contributed most of the propagule pool in the LFH layer, similar to other studies assessing early successional upland forest stands (Archibold 1979; Whittle et al. 1998; Lee 2004). In the LFH donor soil 88% of the propagule density was from seed compared to 59% in the peat donor soil (Tables 2.2 and B.2). The peat donor soil had more propagules emerging from plant vegetative parts (35%) than LFH donor soil (10%). Archibold (1979) found 85% of the soil propagule bank emerging from seeds and spores and 15% from vegetative parts after a fire in a mixed wood stand. In a jack pine community, Whittle et al. (1998) recorded 65% of the emergents from seed and 35% from plant vegetative parts. Differences in propagule type contributions between the two donor sites may be attributed to pre harvest forest type and environmental conditions. The peat donor soil was dominated by *Picea mariana*. These older successional stands tend to have smaller seed banks than more open deciduous stands due to increased predation and senesce through time (Leck et al. 1989). The cold and wet environment in peat may explain the higher contribution from plant vegetative parts compared to the LFH donor soil, since unproductive soil environments favor vegetative regenerating species (Billings and Mooney 1968; Grime 2001). Thus a higher risk may be associated with using peat as a source of propagules for revegetation compared to LFH due to the dependency on plant vegetative parts. Vegetative propagules of many species in peatlands (e.g. *Oxycoccus microcarpus* and *Ledum groenlandicum*) may not survive under dry soil conditions. Natural recovery would be dependent on a few species capable of establishing on drier environments (e.g. *Potentilla norvegica* and *Calamagrostis canadensis*) and long distance dispersers (e.g. *Epilobium angustifolium*).

4.1.2 Species composition, species richness and diversity

The soil propagule bank at both donor sites, for the entire surface horizon, comprised 20 families, 32 genera and 37 species (Table 2.3). Dicotyledons comprised the majority of the species in both donor soils and were most frequent (Table B.3). Unidentified species accounted for 8% and 9% of the total emerged propagules for peat and LFH, respectively.

The LFH donor site had 37 species (range 0 to 13) whereas the peat donor soil contained 19 species (range 0 to 7). Most species were forbs at both donor soils (7 of 19 for Peat and 17 of 37 for LFH) and only two annuals/biennials (*Potentilla norvegica* and *Geranium bicknellii* Britt. (bicknell's geranium)) were found. Two introduced species were present in the LFH donor soil *Sonchus arvense* L. (perennial sow thistle) and *Agropyron repens* (L.) Beauv. (quackgrass) and only *Sonchus arvense* emerged from the peat donor soil (Table B.3).

Species richness, Shannon's diversity index and Sorenson's similarity index to above ground vegetation were greater in the LFH propagule bank for both sampling depths (Table 2.3). The peat treatment had higher evenness values for both depths. In the peat donor site, 9 of the 35 species were found in both above ground vegetation and the soil propagule bank, 11 species were present in the soil propagule bank that were not present in the vegetation at the donor site (Table C.3). The LFH donor site had 22 species found in both the soil propagule bank and above ground vegetation, 15 species were present in the propagule bank that were not part of the 49 species found in the above ground vegetation. The peat donor site had lower similarity coefficients then the LFH donor site when compared to the above ground vegetation and soil propagule bank at the donor sites (Table 2.3). Species richness decreased with increasing depth in both soil propagule banks. The LFH donor site had 35 species in the upper layer and 29 species in the lower layer. The peat donor site had 19 species in the upper layer and 10 species in the lower layer. Diversity (H') was reduced in the lower layers and H' was lower at the peat donor site.

Sorenson's similarity was low at both donor sites, consistent with the majority of research conducted in coniferous and deciduous forests (Omstead and Curtis 1947; Kellman 1970; Thompson and Grime 1979; Qi and Scarratt 1998). In this study *Potentilla norvegica*, *Betula papyrifera* Marsh. (white birch), *Viola adunca* J.E. Smith (early blue violet) and *Viola renifolia* A. Gray (kidney-leaved violet) are a few species that were not found in above ground vegetation for both sites indicating either persistence in the seed bank or species not identified at the donor site. *Betula papyrifera* seed may have dispersed onto the donor site during the sampling year but short-term persistence has been recorded for

this species (Hills and Morris 1992). Although both donor sites were in early seral stages, the similarity was not as high as typically recorded for those stands; however these stands may not have been disturbed as frequently (Archibold 1989; Hills and Morris 1992). Species in the above ground vegetation (e.g. *Picea mariana, Mertensia paniculata* (Ait.) A. Gray (tall lungwort), *Salix* sp.) that were not in the soil propagule bank either required a longer period of cold stratification (Baskin and Baskin 1998) or were transient seeds or roots excluded from the sample.

The decrease in species richness in the lower organic layers has been recorded in previous boreal forest studies (Rydgren and Hestmark 1997; Qi and Scarratt 1998). From a management perspective, soil propagule banks should not be neglected when designing revegetation plans with the use of donor soils. For successful establishment of desired plants on a recent disturbance, species composition and proportion of those species in the soil propagule bank must be known as it will indicate which species may survive as well as help predict which species may become a management problem.

When determining an appropriate donor soil for revegetation, presence of appropriate propagules that will grow in a changed environment on a receptor site is important (Box 2003). Salvaging the LFH layer will add native species to the receptor site that are not present in the peat donor soil. The most important species contributing to the donor soil from the LFH would be those that do not rely upon wind dispersal since dispersal from these species would only be a few meters from the parent plant at the donor site (Chambers and Macmahon 1994) and are capable of surviving on the receiver site.

4.2 Soil Propagule Bank at Receiver Site

4.2.1 Abundance

Sedges had the highest abundance of propagules in all treatments and grasses were the second most abundant (Table 2.4). Sedge and grass species made up a high proportion of the total abundance in the soil propagule bank at each donor site, thus their high abundance within each treatment. The majority of emergents originated from seed; only *Rubus pubescens* Raf. (dewberry) (2.7 plant parts m^{-2} in LFH thick only), *Fragaria*

virginiana (2.7 plant parts m^{-2} in LFH thick only) and *Ribes oxycanthoides* L. (wild gooseberry), 2.7 plant parts m^{-2} in peat thin only) emerged from vegetative parts.

The peat donor soil propagule density was significantly greatest for *Carex* sp. and introduced plants (Table A.3). *Sonchus arvense* was the only introduced species that emerged from the propagule bank samples and was only found in the peat treatments. The thick treatment had significantly greater propagule density than the thin treatment for total plants, sedge, native and perennial species (Table A.3). *Carex* sp., *Agrostis scabra*, *Juncus balticus* Willd. (baltic rush) and *Potentilla norvegica* were the most abundant species for each treatment (Table B.4). These species were present in the soil propagule bank at each donor site (Table B.3).

The large reduction in soil propagule density in all treatments (losses of 96.2% in LFH thin, 94.2% in LFH thick, 91.4 % in peat thin, 77.1% in peat thick) compared to density at the donor sites is consistent with other studies using donor soils on mine sites (Koch et al. 1996; Rokich et al. 2000). Over 99% of plant vegetative parts were lost for each donor soil after application. There was no presence of *Populus tremuloides* in the LFH treatments, a species that was abundant in the above ground vegetation prior to salvaging at the LFH donor site. While the sampling methods may not have captured all vegetative propagules (e.g. pushed roots down), there is still evidence a very large loss occurred. Intense disturbances like soil translocation favor establishment from seeds rather than plant vegetative parts, a possible explanation for this trend (Granström 1986; Rydgren et al. 2004). The large reduction in all propagules could be due to stripping, stockpiling, respreading, freezing and possibly dry soil conditions. Koch et al. (1996) found major losses in seed density throughout the stripping (26%), stockpiling (69%) and respreading procedures (87%).

During the stripping procedure the mineral soil underlying the organic layers was removed at both donor sites. This can significantly affect plant establishment through dilution. Tacey and Glossop (1980) and Rokich et al. (2000) found salvaging deeper within the donor soils profile significantly reduced density of established germinants and number of species at the soil surface. Stockpiling effects can reduce seed density survival

substantially and effects are not related to length of stockpiling (Rockich et al. 2000). Stockpiles in this study were moist when stripped potentially promoting ideal conditions for decomposition, creating anaerobic conditions as well as in situ germination for light independent species, which can lead to propagule death (Rockich et al. 2000). However, the effect of stockpiles overheating in the cold temperate boreal forest has not been well researched.

Spreading procedures may also have reduced propagule abundance, more so for the plant vegetative parts. For example, bulldozer tracks could easily rip apart viable plant vegetative propagules making them no longer viable. The peat treatments could have more losses of plant vegetative propagule because it was respread a second time. However, spreading peat may have mixed salvaged material more evenly, leaving more propagules, such as seed, at the surface compared to the LFH treatment where propagules may be buried deeper than 7.5 cm.

The LFH treatments had an increase in mineral content compared to the peat treatments. The organic layer of the LFH donor soil was much shallower than the peat donor soil but also had high amounts of mineral soil added, therefore increasing the mineral soil content. The increased mineral content in LFH may have reduced seedling emergence. The mineral soil salvaged with the LFH layer was comprised of finer textured particles. In the green house study the clay seemed to create a smooth, light impermeable layer observed when watering the pots, which may have reduced emergence. Seeds in high clay soils will only germinate at the surface and burial at even 1 cm may reduce emergence due to low light penetration (Galinato and Van Der Valk 1986; Fenner 2000). Ter Heerdt et al. (1996) conducted a study on concentrated samples (removal of coarse and fine mineral material) versus non-concentrated samples of clay soils and found concentrated samples had significantly higher total seedling emergence.

4.2.2 Species composition, species richness and diversity

A total of 20 families, 27 genera and 32 species (3 shrubs, 22 herbs, 3 grasses, 1 lily, 1 typha, 2 rush, 1 horsetail) emerged from the samples (Table 2.5). LFH treatments were

more similar (P = 0.0426) to donor site vegetation than peat treatments. LFH thin had 13 and 11 species represented in both the propagule bank and vegetation at the donor site and LFH thick had 17 and 13 species, respectively (Table C.3). Peat thin had 6 species represented in both the propagule bank and vegetation at the donor site and peat thick had 8 and 5 species, respectively (Table C.3). Although not significant when depths were combined, LFH treatments had 29 species emerge and peat treatments had 16. *Vicia americana* Muhl. (american vetch) and *Lathyrus ochroleucus* Hook. (creamy pea-vine) are examples of species important for nitrogen inputs in boreal forest soils, these species were only found in LFH treatments. LFH treatments were significantly more similar to donor site vegetation than peat treatments. The larger loss in similarity in the peat treatments is a reflection of species loss during application and changed environment at the receiver site. Since most of the landscape will be reclaimed to upland plant communities these data show that LFH donor soil will initially set an appropriate trajectory quicker than the peat.

5.0 APPLICATIONS FOR RECLAMATION

Currently the LFH horizon is not salvaged as a donor soil in the AOSR, it gets mixed in with the salvaged peat or over stripped with a deep layer (3 m) of mineral material or not salvaged at all. Salvaging this thin layer is considered an additional reclamation cost due to time invested/volume material salvaged. However, LFH had almost 6,000 more propagules and 18 more species than peat donor soil. Thus the benefits may far outweigh the costs, especially for species that are poor dispersers and are not available at a commercial scale. Adding LFH will provide plant communities more similar to disturbed upland forests initially, because the species are contained within the LFH layer whereas peat donor soil has more hydrophilic species. There is great potential for LFH to supply viable propagules for upland landscapes created from oil sands mining.

Abundance and diversity measures were both reduced in the lower soil layer of both donor soils. While peat will continue to be overstripped with underling mineral soil for soil building properties, research is needed to determine optimal salvage depth of LFH to increase propagule abundance in the surface layer of the receiver site. In Alberta a

minimum of 15 cm of surface soil is recommended for salvaging, this may be too deep to maximize availability of native propagules for revegetation.

Seed and plant vegetative parts of many species in the placed donor soils were substantially reduced in density compared to what was available prior to salvaging. The high death rate of vegetative propagules indicates how severe disturbance through materials handling can affect roots, stolons, rhizomes and suckers. Many species in the boreal forest rely upon vegetative reproduction after disturbance, thus more research should be conducted on timing of salvage and placement. Optimally these operations would occur when carbohydrate reserves are greatest in vegetative reproduction structures. Similarly a large proportion of seed may have been lost from the treatment application procedures. Increased clay in the samples may have prevented many species from germinating in the growth chamber. More research is needed to investigate different sampling methods on boreal forest natural systems and reclaimed systems to get more accurate seed estimates. Effects of all operations from harvesting to placement of donor soil need to be examined to find application procedures that will increase propagule abundance.

The amount and composition of viable soil propagules contained within reapplied donor soils will initially determine the trajectory of early succession on reclaimed lands. Applying donor soils that are heterogeneous in structure at thin application depths to rough surfaces may negatively affect the species composition and abundance of desired propagules used for natural recovery. Operators will have to use caution to avoid substantial admixing. Estimating the species composition and abundance of reapplied donor soils on reclaimed lands can help make decisions about future seedling/planting. However, obtaining accurate estimates might not be achieved if soils contain high amounts of clay. Samples may need to be concentrated if the objective to obtain an accurate estimate to make decisions about future seeding/planting.

6.0 CONCLUSIONS

- The LFH donor soil contained substantially more species and viable propagules than the peat donor soil.
- Species found in LFH donor soil but not peat donor soil were typical of early successional upland forested communities.
- Application depth of LFH and peat was the main factor affecting abundance of plant groups and species numbers.
- Although not statistically significant, LFH treatments contained more species and species typical of upland forests were higher in abundance than peat treatments.
- Over stripping both donor soils and including more mineral soil had the greatest effect on reduced numbers of species and total emergents.
- A high loss in total propagule abundance for each donor soil means many potential areas in the salvaging and application procedures will require more research to better estimate propagule abundance and reduce losses of propagules.

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Figure 2.1. Location of donor and experimental sites at Syncrude Canada Ltd. Base Mine.

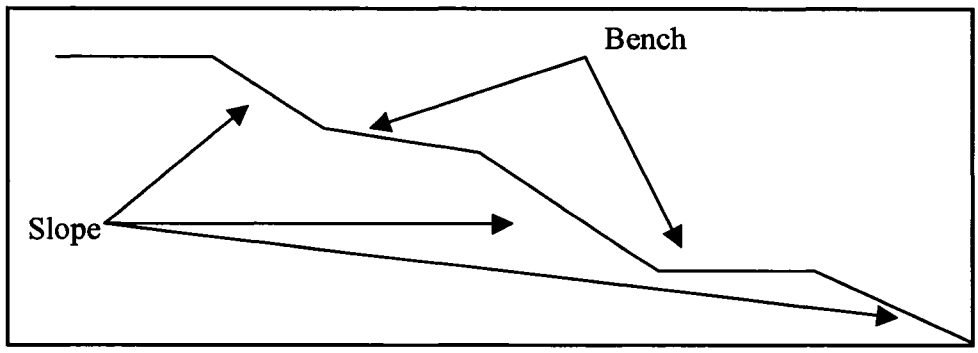

Figure 2.2. Topography consisting of slopes and benches at research site.

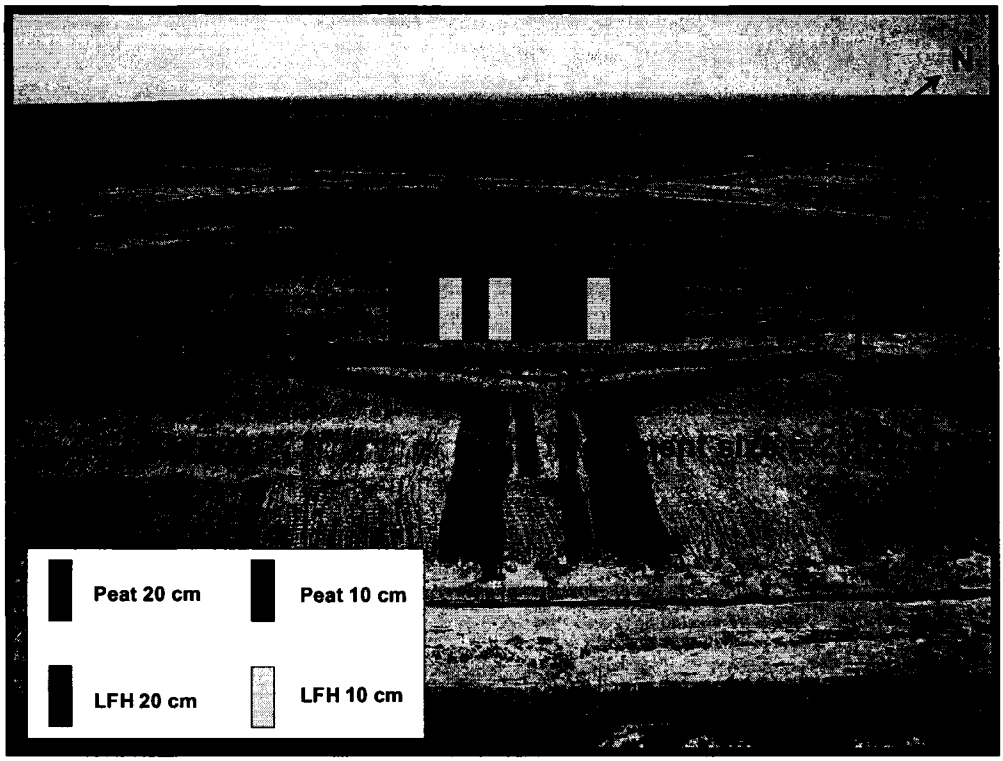

Figure 2.3. Schematic of the experimental design at the receiver site.

Table 2.1. Long term climate normals (1971 to 2000) for Fort Mcmurray (Environment Canada 2003).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Year
Mean Temperature (°C)	-18.8	-13.7	-6.5	3.4	10.4	14.7	16.8	15.3	9.4	2.8	-8.5	-16.5	0.7
Mean Maximum Temperature (°C)	-13.6	-7.6	0.3	10.0	17.4	21.4	23.2	21.9	15.4	7.8	-4.2	-11.6	6.7
Mean Minimum Temperature (°C)	-24.0	-19.8	-13.2	-3.3	3.3	7.9	10.2	8.6	3.3	-2.2	-12.8	-21.4	-5.3
Mean Rainfall (mm)	0.5	0.8	1.6	9.3	34.2	74.8	81.3	72.6	45.0	18.8	2.4	1.1	342.2
Mean Snowfall (cm)	27.0	20.6	20.4	14.5	2.9	0.0	0.0	0.0	2.4	13.1	29.0	25.9	155.8
Total Precipitation (mm)	19.3	15.0	16.1	21.7	36.9	74.8	81.3	72.7	46.8	29.6	22.2	19.3	455.5

Table 2.2. Plant group abundance as emergents m^{-2} within upper, lower and entire sampled surface layers of donor sites.

Plant	Peat			LFH		
Group	Upper	Lower	Entire	Upper	Lower	Entire
Total	2511.1 [a]	1102.8 [b]	3613.9 [B]	5480.8 [a]	3626.6 [b]	9107.5 [A]
	(518.8)	(333.8)	(614.7)	(953.4)	(609.8)	(1203.9)
Grass	424.2	237.5	661.7 [B]	1136.2	772.6	1908.8 [A]
	(234.2)	(220.6)	(329.4)	(504.7)	(334.0)	(625.6)
Sedge	271.5	203.6	475.1 [B]	836.2	645.3	1481.6 [A]
	(118.9)	(86.6)	(146.3)	(161.2)	(126.8)	(225.1)
Rush	203.60	101.80	305.4 [B]	972.6 [a]	218.1 [b]	1190.7 [A]
	(110.8)	(85.9)	(135.0)	(263.0)	(62.0)	(282.5)
Forb	542.9 [a]	220.6 [b]	763.5 [B]	2026.9	1572.5	3599.4 [A]
	(129.0)	(63.1)	(151.9)	(333.3)	(290.1)	(448.2)
Woody	814.4	67.9	882.3	372.7	254.5	627.2
	(421.7)	(32.1)	(418.4)	(144.7)	(132.9)	(269.6)
Pteridophyte	254.5	271.5	526.0	127.3	163.6	290.9
	(141.8)	(121.4)	(197.5)	(82.3)	(72.3)	(148.4)
Native	2273.5 [a]	1035.0 [b]	3308.5 [B]	5071.8 [a]	3281.2 [b]	8353.1 [A]
	(488.5)	(333.3)	(584.1)	(887.8)	(610.0)	(1154.0)
Introduced	17.0	0.0	17.0	63.6	36.4	100.0
	(17.0)	(0.0)	(17.0)	(31.9)	(21.9)	(43.8)
Perennial	2239.6 [a]	967.1 [b]	3206.7 [B]	4590.1 [a]	2754.1 [b]	7344.1 [A]
	(484.2)	(334.0)	(577.6)	(850.4)	(493.0)	(1076.5)
Annual/Biennial	50.9	67.9	118.8 [B]	545.4	563.5	1108.9 [A]
	(28.4)	(40.3)	(52.8)	(128.3)	(259.3)	(303.9)

Numbers in parentheses are standard error of the mean.

Different letters denote significant differences between treatments at $p \leq 0.05$.
Lower case letters denote significant differences between upper and lower stratums within peat or LFH.
Upper case letters denote significant differences of entire strata between peat and LFH.

Table 2.3. Summary of diversity measures in the donor site soil propagule banks within upper, lower and entire surface layers.

	Peat			LFH		
Parameter	Upper	Lower	Entire	Upper	Lower	Entire
Richness	19	10	19	35	29	37
Diversity	2.29	2.14	2.42	2.57	2.54	2.62
Evenness	0.78	0.93	0.82	0.72	0.75	0.72
Similarity	0.30	0.26	0.37	0.4	0.37	0.65

Table 2.4. Treatment effects on emergents m^{-2} of plant groups from the soil propagule bank at the receiver site.

	Peat				LFH			
	Thin		Thick		Thin		Thick	
Groups	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Total	309.4[b]	74.9	828.7[a]	163.5	341.7[b]	136.4	527.3[a]	234.1
Grass	51.1	18.8	177.6	133.4	78.0	38.8	88.8	12.3
Sedge	209.9[ad]	72.8	551.6[ac]	89.0	126.5[bd]	59.0	226.0[bc]	110.2
Rush	2.7	2.7	18.8	11.7	48.4	44.5	43.1	23.9
Forb	43.1	5.4	64.6	23.3	86.1	31.7	150.7	78.
Woody	2.7	2.7	-	-	-	-	10.8	10.8
Pteridophyte	-	-	8.1	4.7	2.7	2.7	2.7	2.7
Native	290.6[b]	70.5	807.1[a]	165.5	317.5[b]	112.3	505.8[a]	236.8
Introduced	10.8	2.7	10.8	2.7	5.4	5.4	2.7	2.7
Perennial	287.9[b]	67.9	788.3[a]	151.5	287.9[b]	127.3	443.9[a]	202.6
Annual/ Biennial	13.5	5.4	29.6	13.5	35.0	23.9	64.6	32.6

SE = standard error of the mean.
Different letters denote significant differences between treatments at $p \leq 0.10$.

Table 2.5. Treatment effects on diversity measurements from the soil propagule bank at the receiver site.

	Peat				LFH			
	Thin		Thick		Thin		Thick	
Diversity index	Mean	S.E	Mean	S.E	Mean	S.E	Mean	S.E.
Richness	5.6	0.7	7.7	1.2	8.3	2.9	13.0	4.0
(H')	1.51	0.19	1.61	0.15	1.51	0.36	2.09	0.15
Evenness	0.88	0.07	0.82	0.12	0.76	0.02	0.85	0.04
Similarity V	0.14[b]	0.04	0.14[b]	0.01	0.27[a]	0.06	0.27[a]	0.08
Similarity P	0.30	0.06	0.40	0.05	0.29	0.05	0.36	0.08
Similarity P (peat vs. LFH)	0.18[b]	0.01	0.23[b]	0.03	0.29[a]	0.05	0.36[a]	0.08
Similarity V (peat vs. LFH)	0.17[b]	0	0.17[b]	0.01	0.27[a]	0.06	0.27[a]	0.08

SE = standard error of the mean.
Different letters denote significant differences between treatments at $p \leq 0.10$.
V = above ground vegetation; P = soil propagule bank.

III. EFFECTS OF DONOR SOILS AND APPLICATION DEPTH ON PLANT ESTABLISHMENT, AND SOIL CHEMICAL/ PHYSICAL PROPERTIES ON A SALINE-SODIC OVERBURDEN PILE IN THE ATHABASCA OIL SANDS REGION

1.0 INTRODUCTION

The goal of reclamation in the Athabasca Oil Sands Region (AOSR) is to return disturbed areas to diverse, self-sustaining boreal forest ecosystems (Oil Sands Revegetation Reclamation Committee 1998). Saline-sodic overburden comprises a large portion of the reclaimed landscape, these materials are associated with marine shales of the Clearwater formation and are inhospitable to most plants due to the high clay content, residual hydrocarbons, salinity and sodicity. Reclamation of disturbances in the AOSR have focused on providing a suitable growing medium for a self-sustaining vegetation cover (Fung and Macyk 2000). A peat-mineral mix, overlying straight mineral soil, is the reclamation surface soil. Revegetation efforts rely on transplanting trees and leaving most native under story species to establish through natural recovery. Low abundance of viable propagules (Fedkenheur and Heacock 1979), dilution of total propagule density from over stripping (Putwain and Gillham 1990), wind dispersed weeds and poor representation of species adaptable to drier soil conditions (Box 2003) make natural recovery problematic.

The large disturbance size makes finding sources of native seed a major challenge. Native seed availability is limited to a few cultivars, mostly grasses; most boreal species are unavailable commercially as seed (Lanoue and Qualizza 2000). A potential source of native propagules exists within the LFH layer from upland forests. LFH is a thin organic horizon composed of fresh, intact, identifiable litter (L), fragmented and fermenting litter (F) and humus (H) with small amounts of moss (Paré et al. 1993). Stripping a thin layer from the surface for large scale operations is currently considered uneconomical. Research has shown this horizon contains numerous propagules for revegetation after natural disturbances, such as fires and tree throw (Whittle et al. 1997). Using LFH as a donor soil could add ecological benefits that far outweigh the cost of salvaging through

additions of upland species tolerant of drier conditions and a more concentrated density of propagules not commercially available (Leck et al. 1989; Qi and Scarrett 1998). Effective use of donor soils as a propagule source for revegetation relies on application depth (Rokich et al. 2000). The few studies assessing application depth of topsoil on mine sites have concluded spreading at thin versus thick depths gives similar results in seedling density and species richness (Rokich et al. 2000; Zhang et al. 2001). Application depth of peat-mineral mix on reclaimed lands in the oil sands is calculated to take into effects of erosion, and organic matter content for nutrient/moisture retention to sustain tree growth (Fedkenheuer 1980). The recommended 20 cm application depth of peat-mineral mix is also used to help eliminate areas where insufficient peat-mineral mix is placed (Oil Sands Vegetation Reclamation Committee 1998). The application depth does not consider the effects of species regeneration from the soil propagule bank.

Using donor soils for natural recovery on mine sites is well documented in subtropical, temperate and arid regions, however its applicability in the boreal forest has not been well researched (Iverson and Wali 1981; Koch et al. 1996; Holmes 2001). Most studies assessing field experiments have done so on small scale plots applied with small equipment or hand tools. Very few studies have attempted to apply random treatments using full size mining equipment. Very little research has been done on natural recovery of boreal plants from LFH donor soils; this layer may prove to solve many problems in finding an abundant source of native seed for the region.

2.0 OBJECTIVES

This research assesses early vascular plant establishment, plant community composition and diversity from in situ propagules from two donor soils commonly found in the AOSR, LFH and peat. Field scale experimental plots were designed to determine responses to field scale equipment and realistic industrial applications. The objectives were to compare propagule sources and placement depth effectiveness at enhancing early establishment of plants. Soil chemical and physical properties were compared between treatments to determine the influence of soil properties on vegetation establishment.

3.0 METHODS

3.1 Research Site Description

The research area is 40 km north of Fort McMurray, Alberta at the Syncrude Canada Ltd. Base Mine site, located within the central mixed-wood subregion of the boreal natural region. The region has a cool temperate climate with short cool summers and long cold winters (Strong and Leggat 1992). Mean annual temperature is 0.7 °C and average annual precipitation is 455.5 mm (Environment Canada 2003). January temperatures (average of −18.8 °C) are typically the lowest while July temperatures (average of 16.8 °C) are the highest (Environment Canada 2003). Annual precipitation as rain is approximately 342.2 mm with 155.8 cm from snow (Table 2.1).

Soils developed on these landforms consist mainly of Luvisols, Gleysols, Brunisols and organic soils (Agriculture Canada Expert on Soil Committee 1987). Upland areas contain soils mainly of the Luvisolic order, while low areas are dominated by organic soils and peaty Gleysolic soils (Yarmuch 2003). Vegetation is composed of a mix of coniferous and deciduous forests. Upland areas typically consist of deciduous forests of *Populus tremuloides* Michx. (trembling aspen) and *Populus balsamifera* L. (balsam poplar), mixed with *Picea glauca* Moench (white spruce). Lowland areas are represented by *Picea mariana* (Mill.) BSP (black spruce) and *Larix laricina* (Du Roi) K. Koch (tamarack) (Fung and Macyk 2000).

3.2 Donor and Receiver Site Descriptions

The donor sites at Syncrude Canada Ltd. were located adjacent to each other, bordering the oil sands extraction pit (Figure 2.1). The area had been cleared (salvaged timber) and drained in 2002 in preparation for mining (Darryl Ramsaran, Personal communication) The total area used for salvaging comprised approximately 9 ha of upland forest (LFH donor site), lowland forest (Peat donor site) and a transitional zone. Estimates of the donor sites area and previous vegetation cover were made in fall 2003 when the propagule bank was sampled. Within the 9 ha area approximately 54% upland forest (LFH donor site), 29% lowland forest (Peat donor site) and 17% transitional. Prior to

timber salvaging the LFH donor site would have been vegetated with trembling aspen with sparse amounts of white spruce. Before the peatland was drained and timber salvaged, the dominant plant cover at the peat donor site would have been from black spruce and ericaceous shrubs. The transitional plant community contained dominant species found in both upland and lowland plant communities

After harvesting and prior to salvaging materials the donor sites were divided into two distinct vegetation communities and soil types, peat and LFH, for salvaging. Just prior to salvaging, the peat donor site was dominated by *Salix* sp. (willows), *Ledum groenlandicum* Oeder (labrador tea), *Oxycoccus microcarpus* Turcz. (small bog cranberry), *Vaccinium vitis-idaea* L. (bog cranberry), *Carex* sp. (sedges) and *Calamagrostis canadensis* (Michx) Beauv. (marsh reed grass). The organic horizon was composed dominantly of peat (> 40 cm) and an underlying saturated mineral soil. The LFH donor site was dominated by *Populus tremuloides*, *Salix* sp., *Rosa acicularis* Lindl. (prickly rose), *Calamagrostis canadensis*, *Carex* sp., *Fragaria virginiana* Duchesne (wild strawberry), *Epilobium angustifolium* L. (fireweed), *Aster ciliolatus* Lindl. (Lindey's aster) and *Petasites palmatus* (Ait.) A. Gray (palmate-leaved colts foot). The soil had a distinct thin LFH layer (mean depth 7.5 cm) with underlying mineral soil consisting of eluviated A horizons , illuviated B horizons and gleyed A and B horizons. A transition zone existed containing a mix of dominant plant species found on both lowland and upland areas.

The receiver site is located on a saline-sodic overburden pile (W1) of Syncrude's Base Mine (Figure 2.1). Saline-sodic overburden materials associated with marine shales of the Clearwater Formation have electrical conductivities greater than 4 dS m^{-1} and a sodium adsorption ratios ranging from 18 to 37 (Fung and Macyk 2000). The research site is located on a southeast aspect, situated on the upper/mid slope of the overburden pile. Topography consists of three forward slopes (7 to 16 %) and two benches (-2 to 4%) (Figure 2.2). Length of slopes and benches vary within and between experimental units, with more variation within. The slope length ranges 18 to 47 m and the length of benches range from 20 to 45 m. The experimental location is representative of an oil sands overburden pile and was selected based on timing of operations and availability. The

southeast aspect provided a large enough area to conduct the experiment, a moderate slope and is representative of the harshest climatic conditions in the area (warm and dry). Construction was completed in late February 2004 with a 90 cm layer of secondary mineral soil (mixture of nonsaline/nonsodic overburden) placed over the overburden.

3.3 Experimental Design, Treatments and Plot Establishment

The experiment was established in a complete randomized design with 4 treatments, a thick application depth (≈20 cm) of peat and LFH and a thin application depth (≈10 cm) of peat and LFH, replicated three times (Figure 2.3). Each treatment was 25 m wide running 150 m parallel to the slope for a total of 12 experimental units. The total size of the site is 300 m wide x 150 m long. Buffers between treatments were not implemented because of operational limitations due to the size of the equipment being used. The limited volumes of LFH and the size of the site allowed a maximum of three replicates. Treatments were large in size to incorporate true responses to the equipment that would be used in normal operations. Treatments were surrounded by peat-mineral mix.

The two donor soils were salvaged in November 2003. The entire peat layer (> 40 cm) of the peat donor soil, with underlying mineral material was salvaged using D10 Caterpillar® bulldozers. The entire LFH layer of the LFH donor soil with approximately 5 to 20 cm of mineral material underlying the LFH layer was salvaged with the same equipment as the peat donor soil. The LFH and peat stockpiles were inspected in December 2003 to select the material to be used in the experiment. Some surface soil from the transition vegetation zone was mixed in with some peat and LFH salvage piles, approximately 5% of some of the piles.

Treatments were applied on February 28 and 29, 2004. Treatments were applied starting from the most westerly treatment and working east (Figure 2.3). Thick treatments received 5 haul truckloads and thin treatments received 3 haul truckloads. Each load contained approximately 160 m^3 of material. Three loads were deemed the minimum-loading rate for thin treatments. Initially two loads were applied to a single treatment receiving a thin application depth to get an average application depth of 10 cm, however,

more than a third of the area was left uncovered resulting in large bare areas that would not be representative of treatment effects. Average application depths were 21.3 cm for thick treatments and 12.8 cm for thin treatments, from here on application depths are referred to as thin and thick.

Treatment application was consistent for each application depth. A Hitachi E2576 hoe was used to load the propagule source material from the stockpile into Hitachi 4500 Euclid haul trucks which transported the material approximately 3 km to the research area. The haul trucks dumped the material beginning at the upper slope and finishing at the lower slope. Prior to spreading donor soil at the receiver site, a large grader formed a road for the haul trucks through the centre and lower portion of the entire experimental area in an east/west direction. The trail was 10 m in width; the middle trail was 105 m north of the southern boundary of the experimental site and the lower trail was 25 m north of the southern boundary of the experimental site. A D10 Caterpillar spread out the material as uniformly as possible for each treatment area from top to bottom in all treatments. Application depth was not uniform within each experimental unit. Limitations of even application depth include uneven surface topography of the secondary mineral soil and physical conditions of the donor soils being applied (e.g. frozen lumps of ice and clay).

During LFH application some experimental units received more transitional material than others. The farthest west thick LFH treatment received one load of transition material. The thick LFH treatment to the east received approximately less than 5% transition material mixed with LFH. Three loads were applied to the second treatment from the west. Spreading peat in winter resulted in large frozen peat lumps with bare ground in between the lumps. These lumps were spread in early June to fill in the bare areas and obtain the desired application depth throughout the replicates using a mid size dozer pulling a 15 m wide pipe. Each experimental unit was spread with one pass down the slope and one pass up the slope.

3.4 Vegetation Sampling

Vegetation was assessed in late July 2004 and 2005 using randomly located transects. A 2.5 m buffer along the east and west boundaries of the experimental unit and a 5 m buffer along the north and south boundaries was delineated to avoid effects of placement during treatment establishment. Vegetation was assessed along each transect using rectangular 0.1 m^2 quadrats placed at 5 m intervals per transect. The number of transects was determined from preliminary assessments conducted in late June of each year. Species area curves (80% of species captured) and running mean/standard deviations were plotted against sample number (level curves). Three transects (84 samples per experimental unit) caught all species in 2004 and 4 transects (112 samples per experimental unit) caught 75 to 80% of the species in 2005, 5 transects was not considered feasible due to time limitations in 2005.

Species density and canopy cover by species were assessed in each quadrat. Assessing density for clonal species was not a problem in 2004 because plants were just establishing, however subjective means for measuring clonal species was taken in 2005. Rhizomatous plants that formed clumps were considered individual plants. Plants reproducing by stolons were difficult to assess, therefore individual crowns along a stolon were counted as an individual plant. Density of *Crepis tectorum* L. (narrow-leaved hawksbeard) seedlings was difficult to assess when densities were greater than 100 plants m^{-2} within a quadrat. When *Crepis tectorum* seedlings were too dense to count, density was estimated by counting individuals within 1% of the 0.1 m^{-2} quadrat. The total density of *Crepis tectorum* seedlings was calculated by multiplying the density within 1% of the quadrat by the total cover within the quadrat. Species nomenclature followed Moss (1993).

Within each quadrat percent mineral soil, organic material from donor soil, woody debris, rock and moss was visually assessed in 2004 and 2005. Mineral soil was delineated by presence of pure mineral material free of any organic material. Organic material included mineral soil mixed with organic material and/or pure organic material and was used to

assess the area that would potentially contain propagules within a quadrat. Woody debris included all types of wood and rock and did not delineate different rock sizes.

3.5 Soils

3.5.1 Sampling protocol

Soils were sampled in early August of each year, in 14 quadrats per experimental unit used for the vegetation assessment. In 2004 one of the three transects was randomly selected and surface samples were taken at 10 m intervals; subsoil was sampled at 20 m intervals. Analyses of the 2004 samples showed that 10 m and 20 m distances had similar variances and means for the analytical data. Therefore in 2005 surface soils were sampled along two transects at 20 m intervals to capture more of the treatment area; 40 m intervals were used for subsoil.

The entire donor soil layer was sampled with a shovel and the underlying 0 to 20 cm of subsoil was sampled using a Dutch auger. Dutch augers were not used to sample the surface soil because of shallow depths and overall dry soil conditions, representative samples could not be taken due to material loss and uneven collection of soil within the profile. Using a shovel, the surface soil within the quadrat was cut in half and samples were taken ensuring an even collection of soil was taken along the profile. In 2005 one sub sample from the third replicate of the LFH thick treatment was lost, thus only 167 samples were taken. Average depths were estimated taking one minimum and one maximum depth of the surface soil horizon from the donor soil/subsoil interface. An area was cleared to expose the secondary mineral soil interface, the Dutch auger was then used to sample to a depth of 20 cm. All samples were placed in plastic bags in coolers containing ice. For the 2004 sampling period average depths were taken at all 1008 vegetation assessment points and in 2005 depths were taken at the 168 soil sample locations.

In 2005, further soil measurements were conducted to determine bulk density and penetration resistance (PR). Bulk density measurements were taken at each slope position (5 samples) per experimental unit with a Uhland core of 7.5 cm diameter and

7.5 cm depth. Volumetric moisture content for each sample was determined by multiplying gravimetric water content of water in the soil by the samples bulk density. Four penetration resistance measurements were taken in the centre of each quadrat prior to soil sampling at 5, 10, 15 and 30 cm using a penetrometer with a 30 ° circular cone and a 20 mm diameter base.

3.5.2 Analytical

Laboratory soil analyses were conducted at EnviroTest Laboratories, Edmonton. In 2004 analyses included percent saturation, pH, electrical conductivity (EC), sodium adsorption ratio (SAR), soluble cations (calcium, potassium, magnesium and sodium) and soluble anions (chloride and sulphate) from a saturated paste extract (Carter 1993). In 2004 total nitrogen (TN) was analyzed using the digestion method with a pretreatment of Devarda's alloy to covert nitrate to ammonium (EnviroTest 2004), available phosphorus was analyzed using the modified Kelowna extract method and total organic carbon (TOC) was determined using the wet oxidation-redox titration method (Carter 1993). A conversion factor of 1.72 multiplied by % TOC was used to estimate percent organic matter. One sample from the LFH thin and one sample from the peat thick treatment, where organic matter content was > 20%, organic matter content was determined by the loss on ignition method at 375 °C (McKeague 1978). Particle size analysis was done using the pipette method for surface soil and the hydrometer method for subsoil (Kalra and Maynard 1991). The pipette method was used in surface soil due to high organic matter content (Carter 1993). Based on correlations with plant growth in 2004, phosphorus and particle size were excluded from the 2005 analyses. Nitrate (NO_3^-), ammonium (NH_4^+) and percent organic matter were added to the 2005 analyses. Nitrate and ammonium was determined using an extraction method with 2.0 M KCL (Carter 2003). Loss on ignition (LOI) was determined at 375 °C. Although the wet oxidation method has a lower coefficient of variance between samples, results from 2004 indicated this method might be underestimating organic matter content in the soils. Therefore LOI was used in 2005 to get more accurate estimates of organic matter content. The wet oxidation method was also conducted in 2005 to compare to the loss on ignition method.

Soil bulk density samples were oven dried at 105 °C to constant weight (48 hr) according to Carter (1993).

3.6 Statistical Analyses

3.6.1 Abundance, diversity indices, soils and species indicator analysis

Prior to analysis of abundance data (percent canopy cover and density) plant species were divided into 11 plant groups based on sum of all plants (total), morphology (grasses, sedges, rushes, woody plants, herbs and pteridophytes), life history strategy (perennial and annual/biennial) and origin (native to North America or introduced) (Table C.1). Unknown monocots and dicots were excluded from all plant groupings except total..

Several measures of diversity were analyzed, including species richness, Shannon's diversity index (*H'*) and evenness. Evenness and H' were calculated with both measures of abundance. Species richness (R), species diversity (H'), evenness (E) and Sorenson's qualitative similarity index (S) to above ground vegetation and propagule bank at the donor sites. Species richness was calculated as total number of species in each experimental unit, transects and quadrats. Species richness excluded unidentified individuals (e.g. *Salix* sp. and *Carex* sp.). Diversity was calculated using the Shannon-Wiener index and evenness was calculated using the formula $E = H'/\log_{10}R$ (Magurran 1988).

Sorenson's similarity index was calculated using the formula $S = 2 \times N/(2 \times N + R1 + R2)$, where N = number of species found in both sites and R1 and R2 is species richness in donor and receiver sites, respectively. Sorenson's similarity index was used to compare to above ground vegetation and soil propagule bank at the donor sites. The peat treatments S were compared to the LFH donor site however LFH treatments were not compared to the peat donor site; the objective of the treatments is to develop an upland plant community not a peat land. Plants that could not be identified to species (unknown grasses, herbs, and woody plants, *Carex* sp. and *Salix* sp.) were excluded in the diversity measures.

Two-way analysis of variance was used to determine significant differences among treatments for the response variables at the receiver site (Zar 1999). Data from the subsamples within each experimental unit were pooled together to give one value per plant group in each experimental unit. Untransformed data was used in the analysis. Shapiro-Wilk's test for normality and Levene's test for equal variances prior to analysis were conducted, with emphases placed on homogeneity of variance. Most variables met homogeneity of variance. Those that did not were transformed using the square root or log transformation. Transformed data were compared with raw data and in most cases transformed data did not alter interpretation of results or results from transformed data made little sense to the raw data. Given the small sample size, tests for normality and homogeneity of variance are sceptical and presentation of both transformed and untransformed data would have complicated interpretation (Finney 1989). Thus all untransformed data were used in analyses. Analyses that had significant interaction effects were further analyzed using Tukeys post hoc test for significant differences between treatments (Zar 1999). A p value of 0.1 was used to determine significant effects. A p of 0.1 was used instead of 0.05 to increase power to offset effects from the small sample size.

Indicator species analysis (Dufrene and Legendre 1997) was performed to determine the prominence of individual species within each treatment using canopy cover as a measure for abundance, analysis was done with PC-ORD 4.01 (McCune and Mefford 1999). Indicator values corresponding to the combined frequency and relative abundance of each species were obtained for each treatment (Boudreault et al. 2002). A Monte Carlo permutation test with 1,000 iterations was used to test significance of the maximum indicator value.

3.6.2 Soil, ground cover and canopy cover relationships

Relationships among soil, ground cover and plant growth were only determined for percent canopy cover in 2005. A spearman's rank correlation coefficient was used to compare the strength of percent canopy cover and density relationships of selected plant groups to soil and ground cover with SPSS 13.0. All plant groups based on morphology

were used in the analysis. All 1,344 quadrats were incorporated in the analysis for ground cover and plant abundance relationships. Correlations were considered significant at $p \leq 0.05$. The majority of environmental variables highly correlated ($R^2 > 0.7$) with other environmental variables and variables with weak correlations ($R^2 < 0.1$) were excluded for simplicity of presentation. Correlations with plant density were similar to correlations with canopy cover, for presentation and reduction of data correlation coefficients with density are not presented in tables.

Relationships between abundance (percent canopy cover) of species to soil, donor soil type and ground cover (% mineral soil) were explored using canonical correspondence analysis with PC-ORD 4.01 (McCune and Mefford 1999). Environmental variables that were highly correlated ($R^2 > 0.7$) with other environmental variables or had little correlation with plant group canopy cover ($R^2 < 0.1$) were excluded from the analysis. Environmental variables used were K, EC, organic matter (LOI), percent mineral soil, topsoil depth and penetration resistance at 5 cm. Percent organic matter determined by the LOI method was used instead of the wet oxidation method because it had higher correlations with canopy cover. Rare species and those that occurred in less than 5% of the 167 samples were removed from the analysis. Of the total 81 species, only 12 species and unknown dicots remained in the analysis after removal. Rare species can significantly affect the results of the analysis and may not reflect any relationship with the environmental variables (McCune and Mefford 1999). Monte Carlo tests for significance between matrices for linear relationships were determined using time of day as random number seeds with 1000 runs. LC scores were used to develop the CCA ordination diagram and row and columns were rescaled using Centered with unit variance. Both species and environmental variables were log transformed to reduce skewness and kurtosis.

4.0 RESULTS AND DISCUSSION

4.1 Vegetation

4.1.1 Density

4.1.1.1 Donor soil

Total densities in each treatment in 2005 were 369, 182, 74 and 59 plants m^{-2} for the LFH thick, LFH thin, peat thick and peat thin, respectively (Figure 3.1). *Crepis tectorum* seedlings were the main contributor to this density in all treatments (Table B.6). Dicotyledons (forbs and woody plants) were denser in both LFH than peat treatments. Differences between the LFH thin and peat treatments were large, however high data variability resulted in non statistical significance for forbs, introduced and annual/biennial plant groups (Table 3.1). The greater densities of native forbs and woody plants in the LFH treatments were due to their high abundance at the LFH donor site. Most of these species, such as *Fragaria virginiana*, *Vicia americana* Muhl. (american vetch), *Rosa acicularis* Lindl. (prickly rose) and *Rubus idaeus* L. (wild red raspberry) are better suited to mesic soil conditions versus some hydrophilic species like *Ledum groenlandicum* and *Oxycoccus microcarpus* found at the peat donor sites. Peat treatments had significantly greater sedge and pteridophyte densities (Table A.4), both common in peatlands, such as poor fens (Beckingham and Archibald 1996). The pteridophyte and sedges were more abundant in the soil propagule bank than in LFH treatments after donor soil application, thus the higher densities in the peat treatments.

The invasion of wind dispersed non-native species, such as *Crepis tectorum* and *Sonchus arvense* L. (perennial sow thistle), is common on anthropogenic disturbances (Hobbs and Huenneke 1992; Pinchak et al. 1995; Peltzer et al. 2000). The substantially higher densities of *Crepis tectorum* seedlings in the LFH treatments is an indication of a better substrate for germination of these species, perhaps due to increased available resources, microsites and initial presence at the donor sites (Table B.3). The increased resource availability such as light and nutrients after a disturbance give these plants an opportunity to establish (Stapanian et al. 1998).

The LFH donor soil prior to stripping had significantly more propagules than the peat donor soil, however the higher plant density in LFH treatments could also be influenced by its increased microtopographic variability relative to the smoother surface of the peat treatments. Johnson and Fryer (1992) conducted a study on effects of surface roughness and concluded seeds remained in place longer on a rough surface than a smoother surface. Since a pipe was not used to smooth out LFH treatments numerous microsites (mounds and dips) were created, varying in size from < 10 cm to > 1 m. This may have created more sites with higher moisture and increased nutrient availability for seed germination. The significance of microsite availability is exemplified in observations of *Crepis tectorum* establishment. During the 2005 assessment hundreds of seeds were attached to new and old plants within the treatments; many seedlings were establishing near these plants as well as in dips, cracks, small rills and near woody debris. All these microsites were substantially more abundant in the LFH treatment. Most *Crepis tectorum* plants appeared to be dispersing on the research site from the north on previously reclaimed area using peat-mineral mix, with all treatments having an equal chance of obtaining seed rain. Microsites in LFH treatments likely held seeds in one spot long enough to germinate.

4.1.1.2 Application depth

Plant density was greater in LFH thick than in LFH thin and similar in peat thick and thin treatments for each plant group (Table 3.1). LFH thick had significantly greater densities than all other treatments for each plant group except sedges, rushes and pteridophytes (Tables A.4). Analysis of interaction effects showed LFH thin did not significantly differ from either peat treatment for most plant groups analyzed, however average densities were considerably higher (Table 3.1). The large increase in *Agrostis scabra* Willd. (tickle grass) and *Carex* sp. in peat treatments resulted in non-significant differences with LFH thin for plant groups containing perennials and native species. Sedges and rushes were more abundant in peat thick than all other treatments and pteridophytes were densest in the peat thin treatment (Table 3.1).

The most dramatic effect of application depth was between LFH thin and thick treatments. Factors other than propagule availability at the soil surface, such as water infiltration, water storage, soil nutrients and soil stabilization will affect emergence (Bowen et al. 2005). The positive response of graminoid establishment in thick treatments may be related to increased water storage and nutrient availability, but also a reflection of the higher densities in the upper topsoil after application (Chapter II, section 4.2.1). Although water infiltration was not measured, more water erosion (rills) was observed within the LFH thin treatments. In both years LFH thick had more phosphorus, total nitrogen and organic matter; in 2005 there was greater percent volumetric moisture and nitrogen (Table 3.8 and 3.6). The greater densities in the LFH thick treatment may also result from less mixing of donor soil with underlying secondary mineral material (subsoil) during application and fewer areas left bare. Results from this study differ from those on restoration projects on mined land in Australia where thick and thin application depths resulted in similar successful emergence from the soil propagule bank because the majority of seeds can only emerge from depths $\leq$ 2 cm (Grant et al. 1996; Rokich et al. 2000). Holmes et al. (2000) found shallow application depths of topsoil had higher densities of native plant species than thick application depths six months after topsoil was placed.

Percent mineral soil was negatively correlated with total plant density in both donor soils, however total plant density was more strongly correlated with LFH treatments ($R^2 = -0.48$, $p < 0.01$) than peat treatments ($R^2 = -0.17$, $p < 0.01$). This was similar to the second growth chamber study, with LFH samples containing high amounts of mineral soil. The high mineral soil content at the soil surface may be preventing light penetration for seeds to germinate. A mineral soil increase on the soil surface could also reduce nutrient availability for seeds (e.g. nitrate) and establishing plants. If admixing can be eliminated, leaving LFH on the surface, then thin and thick application depths may provide similar abundances of plant propagules. Overall the contrasting differences between the two donor soils and application depth suggests how much more responsive LFH as a donor soil was to the application procedure.

Non-significant differences for the majority of plant group densities between the two application depths in peat treatments, supports other studies on effects of application depths (Rokich et al. 2000; Zhang et al. 2001). Both treatments contained similar abundances of most plant groups in the surface of topsoil after application. The slightly higher abundances of graminoid species in peat thick treatments is a reflection of higher abundances within the surface soil, however the slight increase in woody species and *Equisetum arvense* L. (field horsetail) density in the peat thin treatments is difficult to interpret when they were more abundant in 2004 in the peat thick treatment. In general thin and thick treatments can provide similar quantities of propagules for early plant establishment and future applications of peat on saline-sodic overburden piles may need to be adjusted.

4.1.1.3 Time

A very large increase in plant density was found in 2005 over 2004 (Table 3.1). Differences between treatments for plant group abundance were similar in 2004 as 2005 with the exception of the large increase in sedges in the peat treatments. The substantial increase in plant density, excluding recent invaders, in 2005 within peat treatments suggests the importance of weather conditions to species emergence within the soil propagule bank (Table 3.2). Studies on harvested peat show how barren peat soils can create a harsh environment for seedlings due to very dry soil conditions preventing many propagules within the donor soil from establishing (Price 1996; Lavoie et al. 2003). Most species in peat donor soil are wetland species, thus water availability will play an important role in plant colonization and distribution from the soil propagule bank, suggesting abiotic factors have greater influence on plant colonization compared to species within the propagule bank on plant colonization (Keddy and Ellis 1985).

The increased 2005 density within each treatment is also related to seed dormancy. Although available moisture plays a major role in germination, many seeds may have broken physiological dormancy in 2005 (Baskin and Baskin 1998). Another factor increasing density in 2005 is an increase in shoot density from species reproducing vegetatively (e.g. *Epilobium angustifolium* L. (fireweed)).

In 2004 only 0.18%, 0.09%, 0.07% and 0.04% of potential available plants emerged from the propagule bank within the donor sites from LFH thick, LFH thin, peat thick and peat thin treatments, respectively. Even with sufficient precipitation in 2005 and presence of invaders such as *Crepis tectorum*, only, 4%, 2%, 2% and 1.6% of the potential propagule pool at each donor site established in the LFH thick, LFH thin, peat thick and peat thin treatments, respectively.

This large loss in species emergence when there was potentially thousands of propagules available for emergence was explained previously in chapter 2, section 4.2. Operations resulted in a loss of propagules or prevented plants from emerging. However, the dry 2004 (Table 3.2) would have reduced the available surface moisture, possibly preventing germination, or seedlings establishing early may not have had sufficient moisture to successfully establish. Plant vegetative parts near the surface or parts exposed out of the surface would have also suffered greatly due to dry soil conditions, possibly leading to death. Transient seeds (< 1 year viability) that did not emerge in 2004 could have been lost to natural decay (Thompson and Grime 1979). Although there was a substantial decrease in emergence, many seeds could be dormant waiting for the right physical or physiological changes to break dormancy (Hills and Morris 1992) and many propagules may be buried too deep to emerge requiring another disturbance displacing them near the surface. Many propagules may simply not establish due to the dramatic environmental conditions that have changed at the receiver site.

4.1.2 Canopy cover

4.1.2.1 Donor soil

Total canopy cover in 2005 was 36%, 20%, 5% and 6% for LFH thick, LFH thin, peat thick and peat thin, respectively (Figure 3.2). Cover in LFH treatments was mainly comprised of native perennial species; the two dominant species were *Epilobium angustifolium* and *Sonchus arvense* (Table B.7). Species dominance differed slightly in peat treatments, with *Crepis tectorum* and *Epilobium angustifolium* dominant and

codominant species in peat thick and *Sonchus arvensis* codominant in peat thin treatments (Table B.7).

The majority of plant groups analyzed in 2005 had significant interaction effects (Table A.6). For most plant groups both LFH treatments had significantly higher canopy cover than peat treatments (Table 3.3). Pteridophytes were the only plant group with a higher canopy within both peat treatments. For introduced plants in LFH treatments canopy cover was twice as high as peat treatments, however no significant differences were detected between LFH thin and the peat treatments, as a result of high variability between experimental units.

The significantly higher canopy cover in LFH treatments compared to peat-mineral mix treatments is not consistent with two pilot projects that assessed differences between LFH and peat-mineral mix within the AOSR. Both studies were conducted on tailings sand dykes and showed either no substantial increase in canopy cover using LFH or a lower total canopy cover using LFH (Lanoue and Qualizza 1999). In the two pilot projects introduced plants contributed to a lot of the canopy cover in peat-mineral treatments, similar to peat-mineral treatments in this study. Dominant species that accounted for the majority of the canopy cover within LFH treatments at the two pilot projects differed between the two studies. Total canopy cover within the LFH at Suncor was dominantly non-native agronomic species (*Agropyron* sp.); whereas at the Syncrude pilot study LFH treatments were dominated by seeded barley and co-dominated by at least one native species (*Epilobium angustifolium*, *Achillea millefolium* L. (common yarrow) or *Elymus innovatus* Beal (hairy wild rye)). The dominance of wind-dispersed species in each study within peat-mineral mix donor soils was attributed to the aggressive nature of wind-dispersed species present in the surrounding area. These species are better able to adapt to the newly created barren surface soil than propagules in the peat-mineral mix. Results from the Suncor LFH treatment are hard to interpret; few native species emerged from the LFH layer, which is inconsistent from the pilot project conducted at Syncrude and results from this study. Both pilot projects had no replication and the Suncor project gave no detailed data on plant community characteristics prior to salvaging. Thus care should be taken when interpreting these results.

Cover reflects the inherent productivity of a plant community through the amount of ground protection plants are contributing to erosion control, gives a good estimate of ecological significance and reflects ecosystem function (Floyd and Anderson 1987). The higher cover values in LFH treatments are just one means of showing how site productivity is increased when LFH is used as a donor soil. The high canopy cover in LFH treatments can be attributed to the presence of species suited for drier conditions and greater available soil nutrients (Table 3.6).

4.1.2.2 Application depth

Canopy cover for most plant groups responded differently in each donor soil with application depth. LFH thick treatments had significantly greater abundances than LFH thin and peat treatments were similar to each other in canopy cover for each plant group (Table 3.3). LFH thin treatments had significantly greater cover than peat treatments for most plant groups (Table A.6). Thick treatments for both donor soils had higher sedge and rush cover than thin treatments (Table 3.3). The increase in cover of these monocots can be attributed to higher propagule densities near surface and available plant nutrients. Regardless of application depth, in the initial establishment, boreal species will be greater on mesic sites using LFH than peat.

Studies assessing effects of application depth on plant production have shown thick application depths resulted in greater plant biomass and plant cover than shallow application depths due to increased nutrients, higher organic matter and more available moisture (Pinchak et al. 1985; Bowen et al. 2005). While results from the LFH treatments support these results the contrasting differences between donor soils with application depth suggests how more responsive LFH is to application procedures than peat. Similarities in canopy cover between the two application depths for the peat donor soil indicates shallower application depths may be providing herbaceous plants with sufficient nutrients and soil moisture relative to the industry standard 20 cm application depth.

4.1.2.3 Time

Differences in plant group canopy cover between treatments were similar in 2004 and 2005, however cover was substantially lower in 2004 (Table 3.3). In 2004 low precipitation might have had a large impact on the overall low canopy cover for each treatment however differences still existed. Average total canopy cover for LFH thick, LFH thin, peat thick and peat thin treatments were 3.14%, 1.05%, 0.12% and 0.24%, respectively. Canopy cover increased in all treatments in 2005, 10 to 45 times the canopy cover in 2004 (Table 3.3). While available moisture is an important factor in plant productivity, many biotic factors may have been carried over from 2004 into 2005 and factors increased in 2005. Examples of biotic factors that may have had an impact include mycorrhizae associations with plant species, organic matter decomposition and the recycling of nutrients.

4.1.3 Diversity indices

4.1.3.1 Donor soil

In 2005, 79 vascular plant species established in all 12 plots; 49 herbs, 13 shrubs, 10 grasses, 3 trees, 2 horsetails, 1 lily, 1 typha and 1 rush (Table B.6). The LFH treatments had significantly more species than peat treatments and the majority of the diversity indices were significantly greater in LFH treatment, depending on the abundance measurement (Tables 3.4 and A.8). Interaction effects were significant for quadrat richness, however after multiple comparisons, both LFH treatments were still significantly greater than peat treatments (Table A.5). Peat treatments had higher H' ($p = 0.1807$) and E ($p= 0.0515$) values compared to LFH treatments when density was used for abundance (Table 3.3). Because H' is a measurement of species proportional abundance and species evenness, the high density of *Crepis tectorum* seedlings in LFH treatments resulted in lower values of H and E. However, when H' and E were calculated using cover as an abundance measurement LFH treatments had significantly greater values.

Species richness and diversity are used as indicators to describe plant community function and stability (Peterson et al. 1998). However, diversity and species richness may

not be the best indicator of plant community development because additional non-native species can result in an increase in all measurements (Peltzer et al. 2000). Invasive non-native species that contribute to overall diversity can have negative impacts for native plant community development, such as displacing native plants (Hobbs and Huenneke 1992). While LFH treatments resulted in higher species richness in both thin and thick treatments, more so for thick applications, they also had greater densities and cover of introduced species. The majority of non-native species were annuals or short-lived perennials; effects of their abundance on plant community development require future monitoring.

LFH treatments contained over 20 species compared to peat treatments, indicating the use of LFH is developing a more resilient and stable plant community (Table 3.4). Species perform a diverse array of ecological functions, increased richness and diversity often leads to increased ecological stability, resulting in a more resilient and higher functioning plant community (Tilman 1996; Peterson et al. 1998). Tilman (1996) conducted a long-term study on effects of biodiversity on ecosystem stability and concluded that in drought years plant communities with higher species numbers were more drought resistant. Additional species added from LFH is an intrinsic value that is hard to quantify, however its biological value will be obvious once these diverse plant communities persist through periods of environmental stress.

The low similarity of all treatments can be explained by the low similarity of the soil propagule banks to above ground vegetation at the donor sites, which is common in forests (Omstead and Curtis 1947; Kellman 1970; Thompson and Grime 1979; Qi and Scarratt 1998). The significantly higher similarity of LFH treatments to corresponding donor site compared to the peat treatments is simply due to presence of species that were originally at the donor site. Both donor sites were adjacent to each other thus effects are anticipated to have been much greater if donor sites were not in such close proximity, due to less species overlap between donor sites.

4.1.3.2 Application depth

In 2005 the majority of diversity measurements did not significantly differ between application depths for both donor soils (Table A.8). The average species richness per quadrat was not consistent at application depth but was the same for each peat treatment and was significantly greater in LFH thick than LFH thin treatments (Table A.5). Higher species numbers in LFH thick is likely a response to higher concentrations of soil nutrients, organic matter and reduced amounts of mineral soil near the soil surface. The remaining diversity measurements between thin and thick application depths support other studies that assessed effects of application depth on seedling emergence from propagules within the donor soil (Rokich et al. 1997; Zhang et al. 2001). Rokich et al. (2000) showed the majority of species seeded at depths > 2 cm did not emerge. Theoretically a donor soil applied at a thin depth, such as 2 cm, would maximize the use of that particular donor soil. Application depth appears to have little effect on species numbers, however its effects on abundance still remain in question.

4.1.3.3 Time

In 2005, 65 species were captured from all 1344 quadrats assessed and in 2004, 58 species were captured from 1008 quadrats. Shannon diversity index varied between years depending on abundance measure. H' measured with density decreased in 2005 for LFH thick, LFH thin and peat thin treatments, however increased in peat thick. Although measurements in 2005 were taken with an additional transect, similar trends were found using 3 transects. Shannon's diversity index increased for all treatments in 2005 when cover was used as a measure of abundance. The type of measurement used to estimate abundance also influenced estimates of diversity. In 2004 density resulted in higher H' and evenness values for all treatments compared to canopy cover measurements. Because H' is highly responsive to species evenness the type of measurement that most affects evenness will result in greater diversity, such as in this experiment (Peet 1974). For H' estimates with the exclusion of *Crepis tectorum* density H' becomes 2.60, 2.60, 1.76 and 2.00 for LFH thick, LFH thin, Peat thick and Peat thin treatments, respectively. Density measurements can be useful in early stages of plant development, however when plants

are responding more to environmental conditions canopy cover might be the better choice of measurement. The use of density as an abundance measurement in 2005 was limited because defining a counting unit was difficult with the presence of species reproducing vegetatively.

Sorenson's similarity index to both soil propagule bank and above ground vegetation at the donor site decreased slightly in LFH treatments in 2005, but increased in peat treatments. The small decrease in similarity in 2005 within LFH treatments is a combination of invading species, species emerging from the soil propagule bank not included in above ground vegetation of the donor sites and species whose dormancy was either induced or broken and species that were lost from the whole application procedure. *Artemisia biennis* Willd. (biennial sagwort) and *Atriplex subspicata* (Nutt.) Rydb. (salt rush) are examples of annual/biennials that were present north of the research site (unpublished data), seeds of these species would have dispersed onto the site during summer 2004 and spring/early summer 2005. While the additional transect within each experimental unit would increase the chance of capturing additional species, 3 transects also included these species and if they were present in 2004 they were at a morphological stage which made accurate identification difficult.

Dracocephalum parviflorum Nutt. (American dragonhead) was not present in 2004 but occurred in 2005 in fairly high densities in LFH treatments. This species is a persistent seed bank species that thrives on open moist disturbances (Lyon 1976). It was not found in the soil propagule bank prior to salvaging and only in LFH soil propagule banks, indicating cold stratification over winter may have broken its dormancy to allow emergence in the second growth chamber study. The dry 2004 conditions may have induced secondary dormancy preventing from establishing in 2004 (Baskin and Baskin 1998). Species completely absent in all stages of sampling except for above ground vegetation at the donor site were *Pyrola asarifolia* Michx (common pink wintergreen), *Ranunculaceae macounii* Britt. (macooun's butter cup), *Rubus chamaemorus* L. (cloudberry), *Oxycoccus microcarpus* and *Vaccinium vitis-idaea,* suggesting sensitivity to disturbance through application procedures and new environmental conditions at the receiver site. The absence of *Juncus balticus* Willd. (baltic rush) within LFH and peat

treatments in above ground vegetation indicates drier soil conditions might be preventing its emergence, considering it was very abundant in the soil propagule bank.

4.1.4 Indicator species

The majority of species in 2005 were more abundant and frequent in LFH thick than the other treatments as reflected by their significant indicator values in the treatment (Table 3.5). The majority of these species were either greater in the soil propagule bank (e.g. *Potentilla norvegica* and *Calamagrostis canadensis*) or more responsive to better soil conditions for plant growth. Indicator values for *Fragaria virginiana*, *Petasites palmatus*, *Vicia americana* and *Lathyrus ochroleucus* Hook. (creamy-coloured milk vetch) were low, but significant in the LFH thin treatment. *Petasites palmatus*, *Vicia americana* and *Lathyrus ochroleucus* were greater in abundance within the LFH thin treatment, but less competition from other plants, such as *Sonchus arvense* and *Epilobium angustifolium* could have also allowed these species to have more resources for growth. *Equisetum arvense* had almost the same cover in both peat treatments, however it was a significant indicator value in peat thin, suggesting it was more frequent in peat thin treatments. Rare species can significantly affect results of the species indicator analysis (McCune and Grace 2002) thus the presence of *Luzula parvifolia* (Ehrh.) Desv. (wood rush) only in the peat thick treatment resulted in it becoming a significant indicator species. The indicator species analysis clearly shows the majority of species are represented in LFH treatments rather than peat treatments.

4.2 Soils

4.2.1 Donor soil

In general LFH treatments were more nutrient rich than peat treatments. Many interaction effects occurred for most soil chemical parameters analyzed in 2005 (Table A.9). LFH treatments had significantly more phosphorus and soluble potassium than peat treatments (Table 3.6). This supports results from other studies of higher phosphorus in LFH donor soils versus peat-mineral mixes used in the oil sands region for surface soils (Qualizza and Lanoue 1999). Available phosphorus is one of the limiting nutrients in boreal forest

soils (Van Cleve et al. 1983). Potassium is an important nutrient, although not as limiting in forest systems. It helps plants uptake water during water stress and aids in production of adenosine triphosphate (Halvin et al.1999). Using LFH as a donor soil would give landscapes a boost in these nutrients, reducing the need for fertilizer inputs.

Both peat treatments had significantly higher total organic carbon than LFH treatments (Tables 3.6). Deveto et al. (1999) compared C:N ratios between peatlands and upland forests and found peatlands had higher C:N ratio than organic layers of a deciduous forest due to higher organic carbon. The organic carbon decreased with increasing depth in mixed wood forests developed on fine textured soils (Haung and Schoenau 1996). The LFH donor soil mixed with more mineral soil during stripping would also reduce overall carbon content.

Inorganic nitrogen (NO_3^- and NH_4^+) did not significantly differ between donor soils (Table 3.6). The lower C:N ratios in LFH treatments is an indication increased mineralization of organic nitrogen are occurring (Havelin et al. 1999). The non significant differences in inorganic nitrogen between donor soils does not mean LFH did not initially have higher mineral nitrogen; a lot might be in the organic form of live plant material.

There were large differences between the two donor soils for many physical parameters (Table 3.7). Peat treatments had significantly higher organic material on the surface than LFH treatments (Table A.9). LFH treatments had significantly more mineral material, woody debris and moss compared to peat treatments. During salvaging more mineral material was incorporated in LFH donor soil, increasing the mineral soil content and woody debris would have been less diluted due to the shallower salvage depth. Woody species were more frequent and were more abundant in the LFH donor site, thus adding more woody debris than the peat donor soil. The majority of mosses present in the LFH treatments were located in microsites that appeared to be collecting water and areas of high canopy cover. Bryophytes play an important role in the structure and function of boreal forest ecosystems. Bryophytes and other cryptograms are often the first species to colonize primary successional stands (Newmaster and Bell 2002). They play important

roles in moisture retention, soil stabilization, nutrient cycling and seedling establishment (Bonan and Shugart 1989; Newmaster and Bell 2002).

An increase in mineral material indicates less available propagules near the surface for plant establishment as well as less organic matter, both variables related to successful plant community establishment. In natural soil profiles seed and plant vegetative parts decrease with depth (Strong and La Roi 1983; Kramer and Johnson 1987; Warr et al. 1993). Nguyen-Xuan et al. (2000) studied effects of boreal forest floor disturbance and its effects on early species establishment. They found harvesting activities decreased organic material on the soil surface and reduced total vegetation cover. An increase in mineral soil indicated a decrease in available propagules and a reduction in organic matter.

LFH treatments had significantly higher penetration resistance (PR) at 5 cm and 10 cm below the surface than peat treatments (Table A.9), increasing with depth in each treatment (Table 2.7). PR is highly variable because of its relationship with soil moisture and bulk density (Taylor and Gardner 1963). High bulk densities and lower soil moisture result in increased PR, thus the increased PR measurements within LFH treatments. Values greater than 2 MPa can restrict plant root growth (Thompson et al. 1987; Naeth et al. 1991; Lowery and Schuler 1994). PR in each treatment were within or below values recorded for natural and disturbed aspen forests in the boreal to a 30 cm depth (Krzic et al. 2003.). Even though values were below 2 MPa, both CCA (Figure 3.3) and spearman correlation (Tables 3.9 and 3.10) indicate PR as a potential negative parameter to canopy cover in LFH treatments.

Bulk density in the upper 7.5 cm of surface soil was significantly higher ($p = 0.0208$) in LFH than peat treatments (Table 3.8), directly related to higher organic matter and less mineral soil incorporated in peat than LFH donor soils. Soil bulk densities in LFH and peat treatments were comparable to other reclaimed sites within the Athabasca Oil Sands Region. McMillan (2005) reported a bulk density of 0.88 Mg m^{-3} from a surface horizon composed of LFH and a range of values from 0.45 to 1.2 Mg m^{-3} have been recorded in peat-mineral mixes (Lanoue 2001; Yarmuch 2003; McMillan 2005). Bulk density of surface soil in all treatments was much higher than natural LFH layers (0.13 Mg m^{-3}) and

upper surface horizons of peat (0.04 to 0.07 Mg m^{-3}); as expected considering both organic layers were over stripped with mineral soil and spread with dozers (Huang and Schoenau 1996).

4.2.2 Application depth

Similar to plant abundance measurements, soil chemical and physical properties responded differently to application depth depending on donor soil. Few variables were without interaction effects with significant differences between application depths (Table A.9). Thin application treatments had significantly greater bulk densities, higher mineral material on the surface and higher pH. When applying donor soil to thin treatments the bulldozer had to lower its blade, which led to an increase in admixing of secondary mineral soil with donor soil. The increase in mineral material would have influenced the increase in bulk density as mineral soil has a higher bulk density than organic matter.

Both forms of mineral nitrogen were lower in thin treatments, however only ammonium was significantly lower (Table 3.6). Organic matter and nitrogen are so closely linked the reduction of organic matter in thin treatments would have lead to reduced mineral nitrogen. The increase in pH in surface soil is linked to admixing of higher pH secondary mineral soil (Table B.8).

Peat treatments were not significantly different for most soil properties analyzed (Table A.10). Peat thin treatments had significantly higher bulk density and higher mineral soil content on the surface; both properties were affected by applying peat-mineral mix at a thin depth. If all soil chemical and physical properties were similar between treatments and abundance of propagules was greater in peat thick treatments after application, the slightly higher canopy cover in the thin treatment is not easily explainable.

One possible explanation for the higher canopy cover in thin than thick peat treatments is effect of bulk density on soil contact with seeds and roots. The increase in soil bulk density within the upper soil surface horizon in the peat thin treatment may be creating more suitable soil to seed and root contact, which may explain the slightly higher production in peat thin than peat thick treatments. Increased bulk density results in

increased penetration resistance and positive correlations of total cover were found with increased penetration resistance (Table 3.10). Arvidsson (1999), studying effects of soil compaction on nutrient uptake and barley growth showed lowest biomass and yield in soil with the lowest bulk density. Positive effects of soil compaction in relation to plant productivity are reported in the literature (Håkansson 1990). Compaction can increase soil to root contact, increasing nutrient uptake through increases in mass flow transport and higher diffusion coefficients (Kemper et al. 1971). The similar soil chemical and physical properties along with similar plant abundance and diversity measurements indicate that a 20 cm application depth of peat mineral mix may not be necessary on overburden piles with 90 cm of secondary mineral soil, and oil sands operators can conserve more peat by applying application depths at least 40% less than the recommended 20 cm.

Application depth did not respond the same for LFH treatments as peat treatments. The LFH thick application depth provided more nutrients and better soil physical properties for plant establishment compared to the thin application depth (Tables 3.6, 3.7 and 3.8). LFH thin treatments had significantly more mineral soil and rock on the surface, greater EC, higher pH, less organic material, less nutrients (N, P and K), less organic carbon and a lower C:N ratio. All these differences may be due to an increase in admixing LFH donor soil with secondary mineral soil or increased nutrient losses to processes such as leaching and erosion. During the 2005 assessment, plants were more stressed in thin treatments, possibly a combination of lower nutrients and less available moisture. Lower plant densities are directly related to a reduction of LFH material on the surface, the material that contains the majority of propagules. Schwenke et al. (1999) found treatments with mixed topsoil and subsoil layers significantly reduced the original organic carbon content from stripped mined areas, similar effects created when redistributing LFH at a thin depth. Although the LFH thin treatment provided the least organic matter its still within the minimum requirement of 3.0% and 2.5% needed to sustain white spruce and aspen/white spruce forests, respectively (Wilde and Patzer 1940; Wilde 1966).

4.2.3 Time

Donor soil and application depth were the main influences on soil chemical parameters in 2004. However, in 2005 the majority of soil chemical parameters resulted in interaction effects (Table B.9). In 2004 soil chemical properties between the peat treatments had much larger mean differences than 2005, thus the interaction effects in 2005. The majority of anions and cations decreased in surface soil in 2005. Soil pH increased in 2005 in all treatments, however all were still within a good soil rating for plant growth (Macyk et al. 1993).

Ground cover differences between years is difficult to interpret because additional assessors were used in 2005. In 2005 the major changes in ground cover were reduced surface organic material and increased mineral soil, woody debris, rock and moss for most treatments (Table 3.7). Only the LFH thick treatment had a reduction in woody debris. While year to year variation would have accounted for some of the differences between years, there clearly was an increase in mineral soil on the surface for all treatments, which would have reduced overall organic material. The increase in mineral soil in 2005 is a result of different assessors, increased erosion from spring melt and increase in mineral soil from redistribution of clay particles over organic material from raindrops. This mineral soil eroding over organic material reduces emergence from the soil propagule bank. A thin crust of mineral soil may prevent seedlings from emerging and the mineral soil may inhibit light penetration required for many seeds to germinate.

4.3 Soil and Plant Interactions

Plant growth was more responsive in LFH treatments to all environmental variables used in the Spearman's correlation analysis (Tables 3.9 and 3.10). For example, percent mineral soil for ground cover was negatively correlated to density and canopy cover, but LFH had twice as strong a relationship. Soil physical parameters had stronger correlations with plant group canopy cover than soil chemical parameters within LFH treatments. Percent organic material and percent mineral soil on the soil surface, depth of donor soil and percent organic matter had the greatest correlation coefficients in the LFH treatments. Canopy cover of plant groups within peat treatments was correlated strongest

with pH, total nitrogen, organic matter and depth of donor soil (Table 3.9). The majority of plant groups canopy cover and density in both donor soils were negatively correlated with increases in mineral soil, penetration resistance, rock and pH. Canopy cover of plant groups containing perennials was more responsive to all environmental variables whether there was a positive or negative correlation (Tables 3.9 and 3.10). Forbs had stronger correlations with environmental variables in the LFH treatments compared to the majority of the other plant groups. Grasses had higher correlations with soil chemical parameters in the peat treatments, where forbs had stronger correlations to physical parameters.

Canonical correspondence analysis was only conducted for 2005 data, after deleting 5% of plots for rare species and rows containing zeros, only a few plots remained. The ordination diagram shows the non-statistical relationship among sample plots based on their species composition measured as canopy cover (Figure 3.3). The Eigen values of the first three axes only explain 4.8% of the total variance, values 0.17, 0.09 and 0.06 for axis 1 through 3, respectively. The p values for axis 1 through 3 were 0.01, 0.04 and 004, respectively. The arrows in figure 3.3 show environmental gradients, relative importance and inter correlations of the environmental variables. Arrow length is proportional to its importance and the angle between variables reflects their inter correlations. The two different treatments separate differently, the peat donor soils occur on the lower right half of the diagram and consist of only *Equisetum arvense* correlated with organic matter. The LFH treatments are concentrated on the left of the diagram and are represented by most of the species. They are associated with higher values of mineral soil on the surface, higher penetration resistance values and higher concentrations of potassium. The majority of species in LFH are negatively correlated with mineral soil and PR. *Atriplex subspicata,* commonly found on disturbed ground, is more strongly correlated with mineral soil than the other species (Moss 1993).

The negative effects of reduced organic matter near the surface on plant growth have been documented in boreal forests. Nguyen-Xuan et al. (2000) studied effects of boreal forest floor disturbance on early establishment of species. They found harvesting activities decreased organic material on the soil surface and reduced vegetation cover. An

increase in mineral soil indicates a decrease in available propagules and a reduction in soil nutrients (organic matter). In natural soil profiles seed and plant vegetative parts decrease with depth (Strong and La Roi 1983; Kramer and Johnson 1987; Warr et al. 1993). Both donor soils were over stripped and the increase in mineral soil indicates either the underlying mineral soil is on the surface (fewer available propagules for emergence) or secondary soil was incorporated onto the surface. LFH treatments were more responsive to this change than peat treatments. Increases in mineral soil in peat is actually desired to form a good growth medium (Fung and Macyk 2000).

5.0 MANAGEMENT CONSIDERATIONS FOR RECLAMATION

5.1 Vegetation Establishment

The dominance of early successional herbaceous plants in all treatments is typical after large and intense disturbances such as surface mining. There was a large difference in plant community composition between donor soils used in 2005. LFH treatments were mostly composed of perennial plants with a high species richness, peat treatments had a higher proportion of annual plants with significantly lower species richness. The difference between the two donor soils lies with a brief description of how different plant strategies have different adaptations to disturbances.

Rowe (1983) identified five reproductive strategies of boreal plants, each reflecting a different post-fire establishment strategy to maintain their existence. Two of the reproductive groups are based on vegetative reproduction while the remaining three are based on seed reproduction. Evoiders survive disturbance through survival of underground organs (e.g. *Epilobium angustifolium*, *Populus tremuloides*), while resisters have aboveground parts that can withstand surface fires. Invaders (*Crepis tectorum*, *Epilobium angustifolium* and *Sonchus arvense*) have highly wind-dispersed seeds and are short-lived; evaders rely on soil or aerial seed banks (*Geranium bicknellii*, *Rubus idaeus*, *Pinus banksiana*); avoiders rely on seed dispersal but establish in late successional forest. The time, frequency, intensity/severity and size of disturbance dictates which plant strategy will dominate early stages of succession after a disturbance (Granström 1986; Turner et al. 1998). Oliver (1981) suggested weather conditions and competition of the

first establishers play an important role in plant community composition. Past history of a forests disturbance frequency and timing will influence the quality of the donor soil propagule bank. Use of an old forest stand or late successional stand may not be as effective as a younger mid successional stand because old forest stands tend to have a less abundant seed bank (Hills and Morris 1992) and the majority of propagules available for establishment might be the few evoiders that can tolerate a closed canopy or evaders with very long term persistent seed banks (e.g. *Potentilla norvegica*). Both donor sites used in this experiment were recently disturbed, but if a old forest upland donor soil was used, perhaps differences in diversity or abundance of plants between donor soil treatments might not have been as substantial as this study.

Size of disturbance mostly reflects the receiver site in relation to the area that is not adjacent to portions of undisturbed forest. The proportion of area beyond the zone of high propagule input increases as the size increases. The majority of the species establishing past the zone of high propagule input will be invaders. The intensity and severity of a disturbance occurs both at the donor site and the receiver site. Both the intensity and severity of a disturbance relate to propagule availability. The most severe case would be a surface that contained no available propagules at the surface after a disturbance, such as tailings dykes and overburden piles common to mine sites; such a case would favour invaders. If a donor soil containing an abundant and diverse source of propagules capable of establishing at the disturbed site is applied then the issue of propagule availability is less of a concern, such as the placement of LFH. At donor sites the intensity/severity of the disturbance increases when the donor soil is stripped very deep or at a time that physically kills propagules (e.g. time when plants have little carbohydrate reserves). Stripping too deep will dilute the propagule bank with underlying material that contains fewer propagules. If timing is at a stage that does not affect plant vegetative parts then evoiders, avoiders and evaders may all potentially be available for establishment at the receiver site, along with invaders.

Both local weather conditions and competition from plants are an inherent part of a disturbance, because both factors disrupt some part of an ecosystem, plant community, substrate availability or physical environment. For example a dry year after initial

placement of the treatments in 2004 potentially dried out roots of evoiders and made more available space for invaders to occupy the unoccupied space. With a substantial increase in invaders the competition may reduce resources needed for avoiders to emerge from the soil seed bank.

This lengthy discussion about different plant strategies relates to donor soil selection in the oil sands. Peat is a wetland containing mostly wetland species with reliance on natural regeneration to develop a plant community varying with soil moisture conditions. Wet areas will reflect more what is in the soil propagule bank using peat as an amendment, however in topographies and aspects that result in dry soils only a few species adapted to a wide range of soil moisture conditions will establish and if those species do not take advantage of the available space then the plant community will be composed of wind dispersed species, often weedy species that could potentially out compete trees. Relying solely upon natural dispersal mechanisms as a seed source for revegetation may not be appropriate for large disturbances because the majority of species other than ruderals with wind dispersed seeds (e.g. *Epilobium angustifolium*) only disperse several meters from the parent plant (Turner et al. 1998, Chambers and MacMahon 1994). Salvaging LFH for a source of topsoil is highly recommended in the Athabasca Oil Sands Region as not only does it provide a direct route for propagule availability at the disturbed site, but adds species best adapted to drier conditions, such as those found on upland landscapes.

Caution, however, needs to be taken with the use of LFH because it also increased non native species. Non-native species directly compete with native species for nutrients, water, light, pollinators and space; while their presence may reduce erosion and nutrient leaching they can have catastrophic negative effects on native plants and animals (Stapanian et al. 1998). The introduction of non-native plants can often be irreversible. They can permanently become members of the regions biota (Stapanian et al. 1998) altering the nutrient cycle, shifting microbial activity, and providing an unlimited supply of propagules for the next available space (Harrod and Reichard 2001). Methods to increase emergence of native propagules within donor soils could lead to a reduction of available resources for these invaders and increase the propagule pool of native species. An inventory of species in the above ground vegetation and soil propagule bank of a

selected donor soil would help determine what species are a available for establishment on reclaimed lands but also indicate which species may pose threats to establishment of desired species, such as aggressive weeds.

5.2 Soil Organic Matter Measurement

Peat treatments had similar OM and OC in both years. The thick LFH treatments was 4% greater than thin treatments in 2004 and almost 4% greater in 2005, indicating variability of sampling between years (Table 3.5). In 2005 OM measured by LOI was 2 to 6 times higher than wet oxidation OM, however the wet oxidation method had lower standard errors for most treatments (Table 3.5). This is well documented in the literature (Carter 1993) as the wet oxidations method, such as the Walkley Black method, measures easily oxidizable organic C (does not contain C in coal or graphite). While it may underestimate organic carbon, it is more precise than LOI. Soon and Abboud (1991) conducted a study comparing several methods to estimate organic carbon and LOI was more variable compared to the Walkley Black method. LOI resulted in the lowest precision estimates compared to the Walkley Black among replicates for the LFH thin, peat thick and peat thin treatments. Although there was a slight increase in variation, the cost associated with LOI and higher estimates of organic matter make it a commendable method in the AOSR. However, LOI measurements can also overestimate percent organic matter content through weight loss in chemical changes (Warren Greg, personal communication 2006). A more accurate method for determining percent organic matter for soils high in organic matter might be combustion methods that measure evolved $C0_2$ with soil containing a high percentage of organic matter (Warren Greg, personal communication 2006).

6.0 CONCLUSIONS

- LFH had significantly increased plant density, canopy cover and diversity measurements compared to peat treatments.
- Interaction effects for abundance measurements showed different responses to application depth between peat and LFH donor soils.

- LFH treatments were more responsive to application depth, with thick application depths resulting in higher plant density and canopy cover than shallow application depths.
- The peat thick and thin application depth treatments did not differ from each other for the majority of vegetation and soil parameters measured.
- The majority of diversity measurements did not differ between application depth in the LFH and peat treatments.
- Future monitoring is required to make stronger conclusions on the effect application depth has on plant establishment.
- The surface soil in LFH treatments had greater amounts of available phosphorus, potassium, calcium and lower C:N ratios than in peat treatments.
- LFH treatment canopy cover was more responsive to changes in environmental variables measured than were peat treatments.
- The surface soil in the LFH thick treatment had greater amounts of potassium, more organic matter and a lower C:N ratio than the LFH thin treatment.
- Results from this study suggest salvaging the LFH layer developed on fine textured soils can greatly improve the establishment of diverse self-sustaining boreal ecosystems compared to the standard peat-mineral mix.

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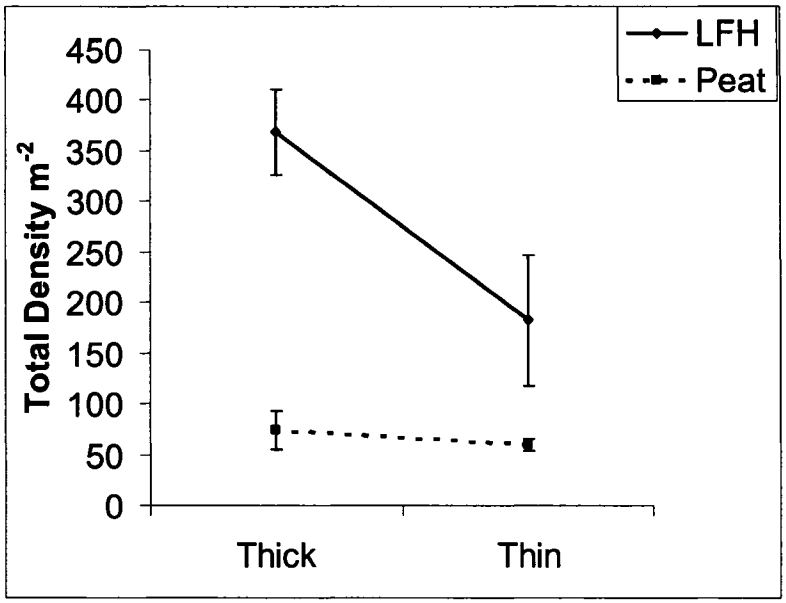

Figure 3.1. Significant interaction effects (p = 0.064) for total density of plants within treatments in 2005.

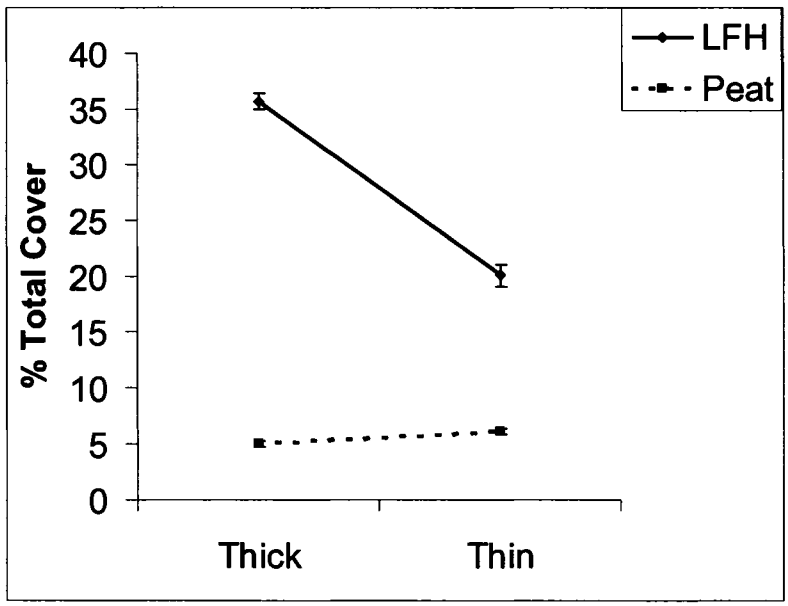

Figure 3.2. Significant interaction effects (p <0.01) for total plant canopy cover within treatments in 2005.

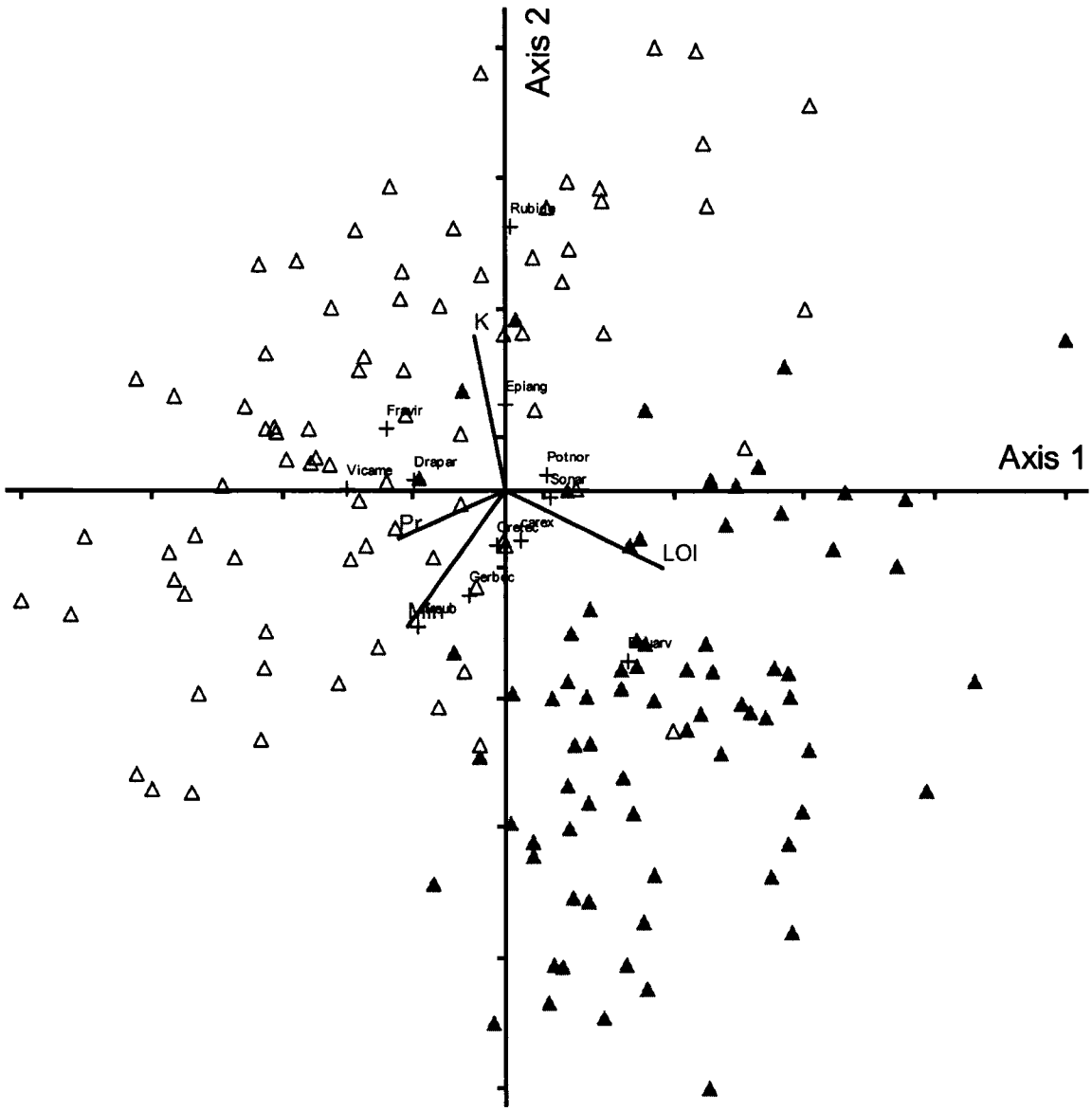

Figure 3.3. Species/environmental biplot from canonical correspondence analysis of the LFH (open triangle) and peat donor soils (solid triangle).

Species codes are as follows: Atrsub, *Atriplex subspicatum*; Carex., *Carex* spp.; Cretec, *Crepis tectorum*; Drapar, *Dracocephalum parviflorum*; Epiang, *Epilobium angustifolium*; Equarv, *Equisetum arvense*; Fravir, *Fragaria virginiana*; Gerbec, *Geranium bicknellii*; Potnor, *Potentilla norvegica*; Rubida, *Rubus idaeus*; Sonarv, *Sonchus arvensis*; Vicame, *Vicia americana*.
K, potassium; Pr, penetration resistance; Min, percent mineral soil; LOI, percent organic matter measured by loss on ignition.

Table 3.1. Mean density (plants m^{-2}) of plant groups within treatments in 2004 and 2005.

	2004				2005			
	LFH		Peat		LFH		Peat	
	Thick	Thin	Thick	Thin	Thick	Thin	Thick	Thin
Total	16.75 (3.38)	8.61 (1.86)	2.54 (0.86)	1.51 (0.51)	368.50[a] (41.90)	182.40[b] (64.80)	74.10[b] (19.00)	59.30[b] (5.60)
Grass	1.51 (0.92)	0.91 (0.08)	0.44 (0.14)	0.08 (0.08)	3.50[a] (1.00)	1.90[b] (0.30)	2.10[a] (0.60)	1.20[b] (0.30)
Sedge	1.31 (0.42)	0.44 (0.38)	0.28 (0.17)	0.08 (0.08)	3.40[c] (0.20)	1.50[d] (0.30)	12.00[a] (0.60)	6.80[b] (3.00)
Rush	- -	- -	- -	- -	- -	- -	0.30 (0.20)	- -
Forb	11.47 (2.17)	5.99 (1.32)	0.28 (0.04)	0.79 (0.24)	359.20[a] (42.80)	176.70[b] (64.70)	54.10[b] (18.10)	45.10[b] (8.20)
Woody	2.26[a] (0.66)	1.15 (0.16)	0.44 (0.21)	0.32 (0.17)	1.70[a] (0.10)	0.80[b] (0.20)	0.20[c] (0.10)	0.60[bc] (0.20)
Pteridophyte	0.20 (0.14)	0.08 (0.04)	0.99 (0.46)	0.24 (0.14)	0.60[b] (0.10)	1.40[b] (0.60)	5.40[a] (1.30)	5.60[a] (1.20)
Native	13.69 (2.89)	7.97 (1.74)	2.34 (0.93)	1.07 (0.31)	38.90[a] (2.30)	23.90[b] (1.40)	25.90[b] (1.50)	20.10[b] (5.10)
Introduced	2.98 (0.45)	0.75 (0.16)	0.04 (0.04)	0.44 (0.28)	329.30[a] (43.20)	158.10[b] (63.90)	47.20[b] (20.40)	38.80[b] (9.10)
Perennial	14.21 (3.20)	7.90 (1.83)	2.30 (0.97)	1.47 (0.53)	44.30[a] (2.70)	24.10[b] (1.80)	23.50[b] (0.30)	19.60[b] (4.00
Annual/ Biennial	2.46 (0.34)	0.60 (0.14)	0.08 (0.08)	0.04 (0.04)	323.90[a] (44.10)	157.90[b] (64.40)	49.70[b] (19.10)	39.30[b] (8.10)

Numbers in parentheses are standard error of the mean.
Different letters denote significant differences between treatments at $p \leq 0.10$.

Table 3.2. Climate data from the Fort McMurray airport weather station for 2004 and 2005 (Environment Canada 2006).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Year
2004													
Mean temperature (°C)	-21.4	-10.6	-6.5	3	5.7	13.3	18	12.7	7.9	1.1	-5.8	-18.5	-0.1
Mean maximum temperature (°C)	-17.2	-3.6	1.3	9.8	12.2	21.4	25.8	20.1	13.7	6.7	-0.6	-12.3	6.4
Mean minimum temperature (°C)	-25.4	-17.5	-14.2	-3.9	-0.9	5.1	10.1	5.2	2	-4.5	-11	-24.7	-6.6
Mean rainfall (mm)	0	3.7	0.9	8.5	49.6	16	36.5	17	54.5	5	2	2.5	196.2
Mean snowfall (cm)	48.7	20.4	20.3	14.5	5	0	0	0	1.5	7	13	24.5	154.9
Total precipitation (mm)	38.3	16.9	15	23	54.6	16	36.5	17	56	12	15	27	327.3
2005													
Mean temperature (°C)	-19.1	-11.6	-4.9	5.3	10	13.8	16.2	14.1	-	-	-	-	3.0
Mean maximum temperature (°C)	-13.2	-4.3	1.8	12	17.6	21.1	23.1	20	-	-	-	-	9.8
Mean minimum temperature (°C)	-24.9	-18.8	-11.7	-1.5	2.2	6.5	9.3	8.1	-	-	-	-	-3.9
Mean Rainfall (mm)	1	0.5	2.5	16	22.5	61	136	64.5	-	-	-	-	304
Mean snowfall (cm)	13.5	10.5	12.5	0.5	0	0	0	0	-	-	-	-	37
Total precipitation (mm)	14.5	11	15	16.5	22.5	61	136	64.5	-	-	-	-	341

Table 3.3. Mean percent canopy cover (per 0.1 m^{-2}) of plant groups within treatments in 2004 and 2005.

	2004				2005			
	LFH		Peat		LFH		Peat	
	Thick	Thin	Thick	Thin	Thick	Thin	Thick	Thin
Total	3.14 (0.68)	1.05 (0.15)	0.12 (0.05)	0.24 (0.07)	35.67[a] (0.71)	20.04[b] (0.97)	5.03[c] (0.29)	6.08[c] (0.27)
Grass	0.14 (0.07)	0.05 (0.00)	0.02 (0.02)	T	2.60[a] (0.12)	1.59[b] (0.34)	0.57[c] (0.15)	0.39[c] (0.08)
Sedge	0.21 (0.16)	T	T	T	1.07 (0.31)	0.59 (0.21)	0.55 (0.01)	0.36 (0.21)
Rush	-	-	-	-	-	-	0.03 (0.02)	-
Forb	2.37 (0.52)	0.79 (0.07)	T	0.16 (0.06)	28.86[a] (0.29)	16.64[b] (1.41)	3.25[c] (0.12)	4.29[c] (0.42)
Woody	0.42 (0.12)	0.21 (0.08)	0.07 (0.03)	0.07 (0.05)	3.00[a] (0.36)	1.00[b] (0.07)	0.08[c] (0.06)	0.47[bc] (0.20)
Pteridophyte	T	T	0.02 (0.02)	T	0.13[b] (0.09)	0.22[b] (0.14)	0.56[a] (0.14)	0.58[a] (0.14)
Native	2.14 (0.51)	0.92 (0.19)	0.11 (0.05)	0.16 (0.06)	23.68[a] (2.00)	15.28[b] (1.03)	3.65[c] (0.54)	3.69[c] (0.79)
Introduced	1.00 (0.35)	0.11 (0.05)	T	0.08 (0.08)	11.93[a] (1.49)	4.72[b] (0.65)	1.34[b] (0.54)	2.38[b] (0.65)
Perennial	2.81 (0.70)	1.02 (0.14)	0.11 (0.05)	0.24 (0.07)	30.88[a] (0.97)	16.60[b] (1.25)	3.13[c] (0.32)	4.04[c] (0.47)
Annual/ Biennial	0.33 (0.02)	0.03 (0.02)	T	T	4.73[a] (0.31)	3.41[b] (0.32)	1.87[c] (0.09)	2.04[c] (0.22)

Numbers in parentheses are standard error of the mean.
Different letters denote significant differences between treatments at $p \leq 0.10$.

Table 3.4. Mean diversity indices for treatments in 2004 and 2005.

	2004				2005			
	LFH		Peat		LFH		Peat	
	Thick	Thin	Thick	Thin	Thick	Thin	Thick	Thin
Quadrat richness	1.19 (0.27)	0.63 (0.11)	0.13 (0.04)	0.08 (0.02)	3.33[a] (0.14)	2.16[b] (0.10)	1.48[c] (0.09)	1.61[c] (0.05)
Transect richness	19.33 (3.18)	17.66 (2.18)	4.67 (0.67)	5.33 (1.33)	38.00[a] (1.15)	34.33[a] (1.45)	17.33[b] (2.67)	17.33[b] (2.33)
Total richness per treatment	- -	- -	- -	- -	49.00[a] (1.53)	47.00[a] (2.65)	24.33[b] (1.86)	24.67[b] (1.98)
Diversity (density)	2.34 (0.19)	2.26 (0.15)	1.17 (0.14)	1.44 (0.13)	0.74[b] (0.13)	0.94[b] (0.28)	1.31[a] (0.46)	1.21[a] (0.17)
Evenness	0.80 (0.05)	0.79 (0.02)	0.78 (0.10)	0.90 (0.04)	0.20[b] (0.03)	0.26[b] (0.08)	0.46[a] (0.14)	0.43[a] (0.08)
Diversity (cover)	1.98 (0.11)	1.92 (0.17)	0.92 (0.18)	0.71 (0.18)	2.31[a] (0.09)	2.49[a] (0.05)	2.14[b] (0.13)	2.04[b] (0.04)
Evenness (cover)	0.68 (0.05)	0.67 (0.03)	0.61 (0.14)	0.43 (0.07)	0.64[b] (0.02)	0.71[b] (0.02)	0.76[a] (0.04)	0.72[a] (0.04)
Similarity P	0.35 (0.02)	0.36 (0.02)	0.23 (0.04)	0.21 (0.04)	0.34[a] (0.01)	0.35[a] (0.01)	0.31[b] (0.02)	0.31[b] (0.01)
Similarity V	0.32 (0.03)	0.34 (0.01)	0.16 (0.02)	0.13 (0.03)	0.32[a] (0.00)	0.32[a] (0.01)	0.22[b] (0.01)	0.23[b] (0.03)
Similarity V (peat vs LFH)	- -	- -	0.15 (0.01)	0.16 (0.04)	- -	- -	0.24 (0.06)	0.22 (0.04)
Similarity P (peat vs LFH)	- -	- -	0.18 (0.02)	0.17 (0.02)	- -	- -	0.30 (0.03)	0.29 (0.01)

Numbers in parentheses are standard error of the mean.
Different letters denote significant differences between treatments at $p \leq 0.10$.
V = above ground vegetation, P = soil propagule bank.

Table 3.5. Species indicator values as measured through percent canopy cover for each treatment in 2005.

Treatment preference Species	Observed Indicator Value	Monte Carlo Simulation mean (±SD) of Indicator Value	p Value
LFH thin			
Fragaria virginiana	13.2	4.5 (0.73)	0.001
Vicia americana	4	1.9 (0.55)	0.002
Petasites palmatus	2.2	1 (0.37)	0.012
Lathyrus ochroleucus	1.8	0.7 (0.27)	0.006
LFH thick			
Crepis tectorum	37.2	20.2 (1.41)	0.001
Sonchus arvensis	27.8	5.9 (0.74)	0.001
Epilobium angustifolium	19.8	6.6 (0.79)	0.001
Rubus idaeus	7	1.3 (0.37)	0.001
Epilobium ciliatum	6.7	1.7 (0.5)	0.001
Potentilla norvegica	6.1	3 (0.58)	0.001
Rubus pubescens	4.6	1.2 (0.39)	0.001
Galium triflorum	3.9	0.7 (0.27)	0.001
Dracocephalum parviflorum	3.6	1.6 (0.44)	0.002
Chenopodium album	3.2	1 (0.38)	0.001
Elymus innovatus	3	1.2 (0.34)	0.003
Trientalis borealis	2.9	1 (0.34)	0.002
Achillea millefolium	2.7	1 (0.37)	0.002
Rosa acicularis	2.7	1 (0.34)	0.002
Agropyron trachycaulum	2.3	0.8 (0.33)	0.005
Lepidium densiflorum	2	0.6 (0.25)	0.002
Viola renifolia	1.8	0.9 (0.36)	0.022
Calamagrostis canadensis	1.6	0.8 (0.32)	0.03
Stellaria longnifolia	1.2	0.5 (0.24)	0.019
Peat thin			
Equisetum arvense	9.7	5 (0.76)	0.001
Atriplex subspicata	4.3	2.6 (0.53)	0.008
Peat thick			
Luzula parviflora	1.2	0.4 (0.2)	0.015

Table 3.6. Mean soil chemical parameters for the surface soil in each treatment in 2004 and 2005.

	2004				2005			
	LFH		Peat		LFH		Peat	
	Thick	Thin	Thick	Thin	Thick	Thin	Thick	Thin
K^+ (mg/kg)	14.62 (1.13)	12.81 (1.89)	5.29 (0.54)	5.26 (0.44)	9.31[a] (0.31)	8.00[b] (0.51)	5.10[c] (1.17)	3.45[d] (0.19)
P_a (mg/kg)	4.38 (0.58)	4.75 (0.52)	2.4 (0.30)	2.25 (0.31)	- -	- -	- -	- -
pH	6.18 (0.06)	6.23 (0.10)	5.8 (0.08)	6.09 (0.15)	6.41[c] (0.10)	6.76[a] (0.08)	6.16[d] (0.06)	6.55[b] (0.18)
EC (dS/m)	1.2 (0.03)	1.5 (0.15)	0.77 (0.10)	1.23 (0.18)	0.85[b] (0.08)	1.26a (0.06)	0.80b (0.13)	0.77b (0.07)
SAR	0.64 (0.13)	0.74 (0.06)	1.11 (0.06)	1.04 (0.09)	0.66 (0.14)	0.94 (0.18)	1.01 (0.06)	0.85 (0.08)
NO_3^- (mg/kg)	- -	- -	- -	- -	3.79 (0.29)	3.34 (0.30)	4.20 (0.64)	3.89 (1.18)
NH_4^+ (mg/kg)	- -	- -	- -	- -	5.50[a] (0.25)	4.26[b] (0.45)	5.47[a] (0.25)	4.80[b] (0.44)
TN (%)	0.32 (0.07)	0.17 (0.03)	0.28 (0.02)	0.26 (0.00)	0.29[a] (0.02)	0.16[b] (0.02)	0.33[a] (0.03)	0.33[a] (0.04)
OM (%)	11.26 (2.24)	7.07 (0.95)	15.48 (1.73)	15.11 (0.78)	9.65[b] (0.61)	5.72[c] (0.59)	15.89[a] (1.25)	15.40[a] (0.11)
TOC (%)	5.57 (0.56)	4.08 (0.55)	8.14 (0.80)	7.83 (0.15)	5.62[b] (0.37)	3.32[c] (0.34)	9.21[a] (0.73)	8.90[a] (0.08)
C:N	20.7 (0.5)	25.0 (2.4)	31.8 (1.1)	32.0 (1.0)	19.6[a] (0.9)	24.4[a] (2.2)	29.7[b] (0.6)	28.9[b] (2.5)

Numbers in parentheses are standard error of the mean.
Different letters denote significant differences between treatments at $p \leq 0.10$.
K^+, potassium; P_a, available phosphorus; EC, electrical conductivity; SAR, sodium adsorption ratio; NO_3^-, nitrate; NH_4^+, ammonium; TN, total nitrogen; OM, organic matter measured by Walkley Black; C:N, total organic carbon to nitrogen ratio; TOC, total organic carbon.

Table 3.7. Mean percent ground cover within each treatment in 2004 and 2005.

		2004				2005			
		LFH		Peat		LFH		Peat	
		Thick	Thin	Thick	Thin	Thick	Thin	Thick	Thin
Mineral	%	32.48 (3.64)	38.31 (6.67)	13.45 (3.10)	13.09 (3.36)	37.12^{b} (0.93)	50.40^{a} (3.66)	21.97^{d} (1.28)	27.79^{c} (5.00)
Organic	%	60.77 (3.56)	56.38 (6.78)	84.23 (2.77)	85.38 (3.43)	56.81^{c} (1.23)	39.51^{d} (3.44)	72.22^{a} (1.36)	66.79^{b} (5.18)
Woody	%	6.41 (0.13)	4.70 (0.44)	1.95 (0.35)	1.25 (0.10)	4.74^{b} (0.18)	7.86^{a} (0.93)	4.73^{b} (0.10)	4.44^{b} (0.30)
Rock	%	0.34 (0.04)	0.60 (0.19)	0.37 (0.09)	0.28 (0.07)	0.89^{b} (0.08)	1.79^{a} (0.25)	1.08^{a} (0.10)	0.97^{b} (0.27)
Moss	%	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.44^{a} (0.25)	0.44^{a} (0.38)	0.003^{b} (0.003)	0.004^{b} (0.003)

Numbers in parentheses are standard error of the mean.
Different letters denote significant differences between treatments at $p \leq 0.10$.

Table 3.8. Mean soil physical parameters within each treatment in 2005.

		LFH		Peat	
		Thick	Thin	Thick	Thin
Db	Mg m^{-3}	0.74^{a} (0.05)	0.92^{a} (0.08)	0.61^{b} (0.07)	0.66^{b} (0.07)
Volumetric moisture	%	0.18^{b} (0.01)	0.19^{b} (0.02)	0.30^{a} (0.03)	0.26^{a} (0.02)
PR 5 cm	kPa	334.9^{a} (32.3)	364.4^{a} (22.2)	204.4^{b} (9.8)	221.6^{b} (37.6)
PR 5 to 10 cm	kPa	443.6^{a} (8.6)	406.5^{a} (30.6)	355.4^{b} (18.1)	325.0^{b} (14.8)
PR 10 to 15 cm	kPa	497.5 (39.7)	510.5 (49.7)	498.2 (48.8)	477.1 (26.6)
PR 15 to 30 cm	kPa	742.6 (50.2)	721.5 (37.7)	663.2 (38.1)	809.3 (26.1)

Numbers in parentheses are standard error of the mean.
Different letters denote significant differences between treatments at $p \leq 0.10$.
Db, Bulk density; PR, penetration resistance.

Table 3.9. Spearman's correlation analysis 2005 canopy cover data for plant groups in LFH treatments.

	Total	Native	Introduced	Perennial	Annual/ Biennial	Grass	Carex	Forb	Woody	Pteridophyte
Mineral	-0.57	-0.51	-0.36	-0.54	-0.30	-0.17	-0.11	-0.52	-0.23	0.08
	< 0.01	< 0.01	< 0.01	<0.01	<0.01	< 0.01	< 0.01	< 0.01	< 0.01	0.04
Organic	0.61	0.54	0.39	0.57	0.32	0.17	0.1	0.56	0.23	-0.08
	< 0.01	< 0.01	< 0.01	<0.01	<0.01	< 0.01	0.01	< 0.01	< 0.01	0.03
Rock	-0.24	-0.19	-0.20	-0.24	-0.12	-0.13	-0.03	-0.22	-0.07	0.09
	< 0.01	< 0.01	< 0.01	<0.01	<0.01	< 0.01	0.37	< 0.01	NS	0.01
Depth	0.43	0.41	0.21	0.44	0.01	-0.02	-0.03	0.43	0.15	-0.05
	< 0.01	< 0.01	0.06	<0.01	0.95	0.86	0.78	< 0.01	0.18	0.65
PR 0 to 5	-0.42	-0.38	-0.14	-0.46	0.05	-0.29	0.03	-0.32	-0.20	0.05
	< 0.01	< 0.01	0.22	<0.01	0.64	0.01	0.79	< 0.01	0.08	0.64
K^+	0.11	0.14	-0.02	0.13	0.01	-0.03	0.14	0.10	0.10	-0.14
	0.31	0.19	0.89	0.25	0.91	0.77	0.20	0.35	0.35	0.22
EC	-0.20	-0.22	-0.06	-0.20	0.02	0.17	0.01	-0.23	0.00	-0.18
	0.08	0.04	0.59	0.07	0.88	0.13	0.90	0.04	0.99	0.11
pH	-0.23	-0.22	-0.14	-0.28	0.02	-0.03	-0.06	-0.25	-0.04	-0.06
	0.04	0.05	0.21	0.01	0.89	0.82	0.60	0.02	0.73	0.61
TN	0.35	0.25	0.33	0.38	<0.01	0.04	0.07	0.33	0.21	-0.02
	< 0.01	0.02	< 0.01	<0.01	0.99	0.74	0.55	< 0.01	0.05	0.86
OM	0.43	0.36	0.32	0.45	0.05	0.02	0.11	0.43	0.21	-0.09
	< 0.01	< 0.01	< 0.01	<0.01	0.65	0.86	0.32	< 0.01	0.06	0.40

PR, penetration resistance; K^+, potassium; EC, electrical conductivity dS m^{-1}; TN, total nitrogen; OM, percent organic matter measured by loss on ignition.

Table 3.10. Spearman's correlation analysis 2005 canopy cover data for plant groups in peat treatments.

	Total	Native	Introduced	Perennial	Annual/ Biennial	Grass	Carex	Forb	Woody	Pteridophyte
Mineral	-0.13	-0.11	-0.11	-0.10	-0.09	-0.08	-0.04	-0.11	-0.10	-0.07
	< 0.01	< 0.01	< 0.01	0.01	0.02	0.05	0.32	< 0.01	0.01	0.07
Organic	0.15	0.13	0.11	0.12	0.10	0.08	0.02	0.13	0.11	0.08
	< 0.01	< 0.01	< 0.01	<0.01	0.01	0.05	0.53	< 0.01	< 0.01	0.03
Rock	-0.15	-0.09	-0.10	-0.12	-0.07	-0.03	-0.08	-0.11	-0.10	-0.05
	< 0.01	0.02	0.01	<0.01	0.07	0.45	0.03	< 0.01	0.01	0.18
Depth	0.21	0.17	0.02	0.15	0.13	0.17	0.07	0.18	0.08	0.13
	0.05	0.12	0.89	0.17	0.23	0.13	0.51	0.10	0.47	0.24
PR 0 to 5	0.12	0.07	-0.04	0.05	0.04	0.20	-0.08	0.07	0.07	-0.08
	0.29	0.50	0.71	0.64	0.73	0.07	0.48	0.55	0.55	0.45
K^+	0.10	0.13	-0.03	0.06	0.08	-0.22	0.12	0.05	-0.04	-0.02
	0.37	0.23	0.81	0.56	0.45	0.05	0.30	0.67	0.71	0.86
EC	0.01	-0.01	0.07	0.06	-0.10	-0.15	0.03	-0.04	-0.12	0.12
	0.90	0.96	0.53	0.60	0.36	0.17	0.76	0.73	0.26	0.27
pH	-0.22	-0.21	-0.04	-0.14	-0.14	-0.23	-0.14	-0.15	-0.13	-0.08
	0.05	0.05	0.69	0.21	0.22	0.04	0.20	0.17	0.25	0.46
TN	0.22	0.17	0.17	0.23	0.10	0.27	0.00	0.16	0.07	0.24
	0.04	0.13	0.13	0.04	0.38	0.01	1.00	0.14	0.53	0.03
OMLOI	0.22	0.21	0.21	0.23	0.12	0.17	0.10	0.18	0.10	0.19
	0.04	0.06	0.06	0.04	0.28	0.11	0.37	0.11	0.36	0.08

PR, penetration resistance; K^+, potassium; EC, electrical conductivity dS m^{-1}; TN, total nitrogen; OM, organic matter measured by loss on ignition.

IV. SYNTHESIS AND FUTURE RESEARCH

1.0 RESEARCH SUMMARY

1.1 Overview

The soil propagule bank from a peat and LFH donor site near the Syncrude Canada Ltd. Base Mine was enumerated in two growth chamber studies. A large scale field experiment applied donor soils at a standard thick application depth and a thin depth. In the following two years, treatments were compared for plant abundance and composition and soils were analyzed for various chemical and physical parameters. The growth chamber study characterized the abundance and composition of the soil propagule bank prior to soil salvaging and after application. The large scale field experiment compared propagule sources and placement depths to determine treatment effect on the early establishment of plants. The operational field scale of the experiment was critical to ensure experimental results were applicable to day to day oil sands mining operations.

1.2 Growth Chamber Study

The LFH donor site contained more species and a greater total abundance of propagules for most of the plant groups analyzed compared peat donor site for the upper and lower stratums sampled. Abundance and diversity indices decreased with increasing depth at both donor sites. The LFH soil propagule bank was more similar to the above ground vegetation. Another large distinction between the donor sites was the contribution of seed and plant vegetative emergence from the total propagule bank. Emergence from plant vegetative parts, largely from ericaceous shrubs, was greater than in the LFH soil propagule bank. Plant vegetative emergence was dominant in the peat donor site. Although this research only assessed one area of each type of soil the higher densities of propagules in the LFH donor site compared to the peat donor site supports past studies on propagule banks (Moore and Wien 1977; Archibald 1979; Qi and Scarratt 1998).

The soil propagule bank at the receiver site was substantially less abundant and had fewer species emerge than the donor sites. Propagule abundance was greatest in peat and thick treatments. Only plant groupings containing monocotyledons were different between

treatments, smaller p values were associated with application depth. Over stripping both donor soils had the greatest effect on reduced numbers of species and total emergents. Many other potential areas in the entire operations of applying donor soils would have led to the cumulative loss of propagules near the surface in each treatment. Future research is needed to locate the major areas of propagule reduction.

1.3 Field Study

LFH treatments provided greater plant abundance and diversity indices than peat treatments. The surface soil in LFH treatments was more fertile than the peat treatments. Application depth in peat treatments had little effect on most vegetation and soil parameters, however LFH thick treatments provided significantly greater densities, canopy cover and a more fertile growing medium than LFH thin treatments. Application depth had little impact on diversity indices for both donor soils. Canopy cover of most plant groups was more responsive to the environmental variables within LFH treatments. Physical parameters, such as surface organic material, resulted in the highest correlations in LFH treatments and total nitrogen and organic matter were highest in peat treatments. While both application depths of LFH resulted in higher canopy cover than both peat application depths, much more research is required on salvaging and application of LFH donor soil to increase emergence from the potential total propagule pool.

2.0 Applications For Reclamation

Results from this research show a clear distinction between the two donor soils in initial plant establishment. LFH outperformed the standard peat-mineral mix used in the Athabasca Oil Sands Region. The implications of the findings are straight forward, the LFH layer should be salvaged and used as a source for propagules on disturbances to be reclaimed to upland forest communities. The LFH layer contains species suitable for more mesic soil conditions and at greater densities. Most species within the peat donor soil were hydrophilic species, they will be less likely to establish on site.

While recommendations for applying a peat-mineral mix suggest a 20 cm application depth, results from this study proposes this rate can be reduced at least 40%. Caution

needs to be taken with this reduction because of the early stages of development of the plant community. Rarely is it possible to get independent replicates when applying treatments at such a large size and few experiments are only monitored for several years, thus long term monitoring will be required to make firm conclusions on application depth.

Differences of most parameters between application depths using LFH donor soil and the relationships between environmental parameters and canopy cover have led to many interesting ideas and/or applications of its use for reclamation; not just for oil sands region but potentially the entire boreal region. The increased plant and plant group abundance in the LFH thick treatment is likely the result of more soil nutrients and fewer negative soil physical parameters (e.g. increases in surface mineral soil, bulk density and penetration resistance) compared to the thin application depth. Soil nutrients can be managed after the donor soils have been applied, but the soil physical parameters affected at the receiver site from initial stripping and application are likely irreversible.

The recommended salvage depth of boreal forest soils with an LFH layer includes the LFH layer plus up to an additional 15 cm of underlying mineral soil, similar to what occurred in this experiment (Alberta Environment 1995). The implications of over salvaging the LFH layer are increased mineral soil on the surface of any receiver site. While over stripping this material may reduce costs in salvaging and increase volumes used for placement, the impacts of reducing propagule abundance at the donor site for establishment may offset the benefits of these factors. Effects of applying a thin application of LFH on a rough surface of mineral soil were similar to over stripping because the mineral soil gets further added with the LFH donor soil. If objectives are to develop diverse native plant communities and LFH is of limited supply, its use will be maximized by applying at thin application depths and the benefits of applying at thin depths may be maximized if admixing with mineral soil is minimized. If increased canopy cover of species emerging from the soil propagule bank is desired, then possibly applying fertilizer or applying a thin layer of LFH on a substrate that can provide the establishing plants with nutrients may be an option.

3.0 FUTURE RESEARCH

This research has recognized the importance of the LFH layer in providing oil sands companies a source of native propagules for revegetation that otherwise would never be available for commercial applications. Ways to maximize its use must be found because its availability is low compared to peat and an application of 20 cm may not be utilizing its potential in an efficient manner. Recommendations for future research from the results obtained are listed below.

- Salvage depth. Increased salvage depth will result in dilution of the LFH layer, which contains the majority of the propagules. The increase in mineral soil from fine textured parent material may restrict seed germination if used as a donor soil. The majority of mineral soils in the boreal forest are salvaged to depths of 15 cm or greater. Effectiveness of natural recovery from the soil propagule bank may be inhibited due to over stripping. Thus, research is necessary to determine if over stripping the LFH layer with underlying mineral soil affects overall performance of LFH as a seed source on reclaimed lands.
- LFH patches to allow species egress. The majority of boreal species do not disperse long distances, other than species bearing wind dispersal mechanisms (e.g. pappus on seeds of many dicotyledon species). However, even at short dispersal distances allowing species to establish in patches of LFH onto adjacent peat-mineral mixes can help maximize species use for revegetation. Research is needed to determine if placing LFH in patches can increase the overall diversity and abundance of upland species on reclaimed lands. Research is also required to determine how patch size affects the overall success in species survival within patches and dispersal out patches.
- Application depth/inoculation. Applying a donor soil at 5, 10 or 20 cm could result in similar seed abundance near the surface if materials are not admixed with soil during placement, thus similar potential for plant emergence. Research is required to find optimal ways to apply LFH at thin depths but also provide plants with a substrate for moisture and nutrients.
- Stockpiling effects on propagules. Many seeds and plant vegetative parts would have died after stockpiling. The effects of stockpiling on propagule survival to make

appropriate decisions on duration of stockpiling, size of stockpiles and impacts of stockpiles to species and soil properties must be determined.

- Amendments to increase seed germination. Many seeds remain dormant in the donor soil, which could result in a positive and a negative situation. Dormant seeds will provide a more resilient plant community; future disturbances will create favourable conditions for these seeds to establish, this is necessary for self-sustaining ecosystems. However, dormant native seeds that do not establish early enough may not remain viable long enough to withstand competition from many native and non native invader species. Practical solutions to breaking dormancy of native species will reduce available resources for these invaders and possibly create a more desirable plant community. The additions of smoke water and nitrate fertilizer have increased germination of dormant seeds in many other ecosystems, its applicability also needs to be assessed in the boreal forest (Van Staden and Brown 1997; Baskin and Baskin 1998).
- Irrigation. The dry spring and summer of 2004 would have resulted in a large reduction in species emergence, possibly death. Irrigation of LFH in the initial stages may be necessary in very dry years to help native species get a competitive advantage in utilizing available resources.
- Seed bank classification. Information is lacking on most boreal species, other than trees, for seed viability, germination, dormancy and seed longevity. A seed bank classification system must be created in the boreal forest to help industry understand how operations affects certain species and also help create situations to maximize the propagule bank for revegetation.

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APPENDIX A. P VALUES FOR ANALYSES CONDUCTED FOR CHAPTER II AND III.

Table A.1. P values for plant groups soil propagule density m^{-2} between donor sites in the entire sampled soil layer.

Groups	P Value
Total	0.0016
Grass	0.0134
Sedge	0.0012
Rush	0.0432
Forb	<0.0001
Woody	0.8537
Pteridophyte	0.2037
Native	0.0035
Introduced	0.2249
Perennial	0.0106
Annual/Biennial	0.0024

Table A.2. P values for plant groups soil propagule density m^{-2} between the upper and lower soil layers for each donor site.

Groups	LFH	Peat
Total	0.0432	0.0069
Grass	0.5637	0.3750
Sedge	0.4890	0.6602
Rush	0.0075	0.3281
Forb	0.1830	0.0295
Woody	0.1105	0.1108
Pteridophyte	0.4652	0.9063
Native	0.0232	0.0104
Introduced	0.4795	0.3173
Perennial	0.0326	0.0090
Annual/Biennial	0.3381	0.7055

Table A.3. P values from treatment and interaction effects on plant groups emergence density m^{-2} at the receiver site.

Parameter	Treatment	Depth	Interaction
Total	0.4320	0.0620	0.3349
Grass	0.6717	0.3580	0.4348
Sedge	0.0426	0.0317	0.1917
Rush	0.2146	0.8409	0.6892
Forb	0.1784	0.3542	0.6362
Woody	0.5447	0.5447	0.2415
Pteridophyte	0.6666	0.2165	0.2165
Native	0.4131	0.0574	0.3320
Introduced	0.0955	0.7153	0.7153
Perennial	0.2710	0.0542	0.2710
Annual/Biennial	0.2249	0.3181	0.7622
Richness	0.1576	0.2301	0.6174
Diversity (H')	0.3318	0.1782	0.3237
Evenness	0.6218	0.8500	0.3656
Similarity V	0.0426	0.9771	0.9705
Similarity P	0.7095	0.1930	0.8458
Similarity P (peat vs. LFH)	0.0354	0.2470	0.7997
Similarity V (peat vs. LFH)	0.0845	0.9997	0.9440

Similarity V, Similarity index to vegetation at the donor site.
Similarity P, Similarity index to soil propagule bank at the donor site.

Table A.4. P values for plant groupings mean density m^{-2} in 2005.

	Treatment	Depth	Interaction
Total	0.0008	0.0357	0.0638
Grass	0.1307	0.0730	0.6319
Sedge	0.0021	0.0535	0.3202
Rush	0.1875	0.1875	0.1875
Forb	0.0006	0.0437	0.0621
Woody	0.0004	0.0940	0.0034
Pteridophyte	0.0011	0.5699	0.7746
Introduced	0.0224	0.0081	0.1631
Native	0.0011	0.0558	0.0773
Perennial	0.0012	0.0016	0.0130
Annual/Biennial	0.0012	0.0605	0.0903

Table A.5. Tukeys post hoc multiple comparison for plant groupings mean density m^{-2} in 2005 and quadrat richness.

	LFH thick vs LFH thin	LFH thick vs Peat thick	LFH thick vs Peat thin	LFH thin vs Peat thick	LFH thin vs Peat thin	Peat thick vs Peat thin
Total	0.0434	0.0035	0.0026	0.2922	0.2073	0.9931
Forb	0.0473	0.0028	0.0023	0.2088	0.1698	0.9986
Woody	0.0121	0.0005	0.0025	0.0848	0.6029	0.4518
Native	0.0304	0.0592	0.0090	0.9626	0.8001	0.5408
Introduced	0.0655	0.0049	0.0041	0.2817	0.2324	0.9987
Perennial	0.0024	0.0020	0.0006	0.9978	0.6266	0.7266
Annual/ Biennial	0.0760	0.0059	0.0047	0.3015	0.2383	0.9977
Quadrat richness	0.0002	0.0000	0.0000	0.0061	0.0197	0.8076

Table A.6. P values for average percent canopy cover for plant groupings in 2005.

	Treatment	Depth	Interaction
Total	<0.0001	<0.0001	<0.0001
Grass	<0.0001	0.0171	0.0709
Sedge	0.1173	0.1565	0.5142
Rush	0.1388	0.1388	0.1388
Forb	<0.0001	<0.0001	<0.0001
Woody	<0.0001	0.0048	0.0004
Pteridophyte	0.0156	0.6544	0.7805
Introduced	<0.0001	0.0090	0.0086
Native	0.0001	0.0099	0.0020
Perennial	<0.0001	<0.0001	<0.0001
Annual/Biennial	<0.0001	0.0518	0.0185

Table A.7. Tukeys post hoc multiple comparison for mean percent canopy cover plant groupings in 2005.

	LFH thick vs LFH thin	LFH thick vs Peat thick	LFH thick vs Peat thin	LFH thin vs Peat thick	LFH thin vs Peat thin	Peat thick vs Peat thin
Total	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.6589
Grass	0.0291	0.0004	0.0002	0.0288	0.0120	0.9135
Forb	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.7696
Woody	0.0006	<0.0001	0.0001	0.0556	0.3468	0.5637
Native	0.0055	<0.0001	<0.0001	0.0007	0.0007	1.0000
Introduced	0.0024	0.0002	0.0004	0.1152	0.3369	0.8511
Perennial	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.8686
Annual/ Biennial	0.0251	0.0002	0.0003	0.0111	0.0208	0.9635

Table A.8. P values for diversity indices in 2005.

	Treatment	Depth	Interaction
Richness quadrat	0.0000	0.0009	0.0002
Richness treatment	<0.0001	0.3861	0.3861
Richness total	<0.0001	0.6325	0.8100
Diversity (density)	0.1807	0.8761	0.6116
Evenness (density)	0.0487	0.8566	0.6376
Diversity (cover)	0.0066	0.6539	0.1333
Evenness (cover)	0.0515	0.6186	0.1232
Similarity V	0.0099	0.7772	0.7362
Similarity P	0.0002	0.6034	0.6445
Similarity of V (Peat vs LFH)	0.0001	0.4268	0.3902
Similarity of P (Peat vs LFH)	0.0140	0.9910	0.6438

Similarity V, Similarity index to vegetation at the donor site.
Similarity P, Similarity index to soil propagule bank at the donor site.

Table A.9. P values for surface soil chemical and physical parameters in 2005.

	Treatment	Depth	Interaction
Chemical			
Chloride (mg/L)	0.0037	0.1111	0.0138
Calcium (mg/L)	0.0010	0.0146	0.0065
Potassium (mg/L)	0.0002	0.0572	0.8062
Magnesium (mg/L)	0.0199	0.1712	0.0375
Sodium (mg/L)	0.4668	0.3234	0.0612
Sulphate (mg/L)	0.1501	0.1103	0.0360
Phosphorus (2004, mg/kg)	0.0010	0.8150	0.5665
Total nitrogen (%)	0.0094	0.0678	0.0822
Nitrate (mg/kg)	0.3519	0.4235	0.6970
Ammonium (mg/kg)	0.5003	0.0305	0.4477
Total organic carbon (%)	0.0000	0.0189	0.0553
Organic matter WB (%)	0.0000	0.0195	0.0526
Carbon:nitrogen	0.0029	0.2713	0.1471
Organic matter LOI (%)	0.0000	0.0674	0.0600
pH	0.0660	0.0105	0.8759
Electrical conductivity dS/m	0.0181	0.0618	0.0377
Sodium adsorption ratio	0.3194	0.6804	0.1109
Physical			
Mineral (%)	0.0004	0.0173	0.2767
Organic (%)	0.0002	0.0080	0.1043
Woody (%)	0.0090	0.0223	0.0093
Rock (%)	0.1481	0.0809	0.0328
Moss (%)	0.0936	0.9950	0.9899
Percent saturation (%)	0.0000	0.4264	0.7401
Bulk density (Mg m^{-3})	0.0208	0.1280	0.4039
Volumetric moisture (%)	0.0013	0.5371	0.2058
Penetration resistance 0 to 5 cm (kPa)	0.0010	0.4367	0.8543
Penetration resistance 5 to 10 cm (kPa)	0.0064	0.2288	0.9213
Penetration resistance 10 to 15 cm (kPa)	0.8537	0.9415	0.6082
Penetration resistance 15 to 30 cm (kPa)	0.8969	0.1452	0.0693

WB, % organic matter determined by the Walkley Black method; LOI, % organic matter determined by loss on ignition.

Table A.10. Tukeys post hoc multiple comparisons for surface soil interactions in 2005.

	LFH thick vs LFH thin	LFH thick vs Peat thick	LFH thick vs Peat thin	LFH thin vs Peat thick	LFH thin vs Peat thin	Peat thick vs Peat thin
Calcium	0.0061	0.7764	0.5612	0.0020	0.0013	0.9783
Chloride	0.7788	0.9149	0.0140	0.4319	0.0042	0.0336
Magnesium	0.0853	0.9910	0.7611	0.0568	0.0215	0.8950
Sodium	0.1812	0.7545	0.9968	0.5964	0.2381	0.8549
Sulphate	0.0620	0.9110	0.9988	0.1555	0.0760	0.9543
Total nitrogen	0.0770	0.7555	0.8009	0.0192	0.0216	0.9997
Organic carbon	0.0265	0.0020	0.0036	0.0001	0.0001	0.9593
WB OM	0.0261	0.0018	0.0029	0.0001	0.0001	0.9673
LOI OM	0.0626	0.0116	0.0108	0.0004	0.0004	0.9999
EC	0.0440	0.9861	0.9413	0.0276	0.0203	0.9957
Woody	0.0098	1.0000	0.9722	0.0096	0.0057	0.9749
Rock	0.0478	0.8981	0.9917	0.1264	0.0710	0.9753

WB OM, total organic matter measured by the Walkley black method; LOI, total organic matter measured by the loss on ignition method; EC, electrical conductivity.

APPENDIX B. ADDITIONAL TABLES FOR CHAPTER II AND III

Table B.1. Propagule density m^{-2} of extraneous plant groupings within donor sites upper, lower and entire sampled surface layers.

	Peat		LFH		Peat	LFH
Groupings	Upper	Lower	Upper	Lower	Entire	Entire
Monocotyledon	899.2 (291.5)	542.9 (310.6)	2954.0 (713.6)	1636.1 (436.3)	1442.2 (438.0)	4590.1 (900.1)
Dicotyledon	1357.3 (412.2)	288.4 (75.9)	2399.6 (372.3)	1827.0 (308.2)	1645.8 (410.3)	4226.5 (522.5)
Native grass	407.2 (234.6)	237.5 (220.6)	1108.9 (500.5)	736.2 (333.5)	644.7 (330.1)	1845.1 (617.0)
Introduced grass	-	-	27.3 (27.3)	-	-	27.3 (27.3)
Native forb	322.4 (75.2)	152.7 (49.7)	1645.2 (258.4)	1263.4 (281.5)	475.1 (94.3)	2908.6 (387.8)
Introduced forb	17.0 (17.0)	-	36.4 (17.7)	36.4 (21.9)	17.0 (17.0)	72.7 (35.4)
Perennial graminoid	882.3 (292.8)	542.9 (310.6)	2944.9 (711.8)	1599.7 (435.7)	1425.2 (436.8)	4544.6 (899.0)
Perennial forb	305.4 (71.6)	84.8 (35.2)	1299.8 (242.6)	890.7 (189.4)	390.2 (86.9)	2190.5 (366.4)
Annual/Biennial forb	50.9 (28.4)	67.9 (40.3)	545.4 (128.3)	563.5 (259.3)	118.8 (52.8)	1108.9 (303.9)

Numbers in parentheses are standard error of the mean.

Table B.2. Propagule density m^{-2} for plant groups at the donor sites for the upper and lower soil layer.

	Peat						LFH					
	Upper Layer			Lower Layer			Upper Layer			Lower Layer		
	S	V	U	S	V	U	S	V	U	S	V	U
Total	1476	882	153	662	390	51	4854	545	82	3163	364	100
Monocotyledon	831	51	17	407	136	-	2772	182	-	1509	127	-
Dicotyledon	628	594	136	221	17	51	1972	345	82	1582	145	100
Grass	356	51	17	102	136	-	973	164	-	700	73	-
Sedge	272	-	-	204	-	-	827	9	-	591	55	-
Rush	204	-	-	102	-	-	964	9	-	218	-	-
Forb	526	17	-	187	-	34	1845	136	46	1418	73	82
Woody	102	577	136	34	17	17	127	209	36	164	73	18
Pteridophyte	17	238	-	34	238	-	109	18	-	73	91	0
Native	1256	882	136	628	390	17	4517	518	36	2872	345	64
Introduced	17	-	-	-	-	-	36	27	-	36	-	-
Native grass	356	51	-	102	136	-	973	136	-	682	55	-
Introduced grass	-	-	-	-	-	-	-	27	-	-	-	-
Native forb	305	17	-	153	-	-	1273	136	-	1145	73	45
Introduced forb	17	-	-	-	-	-	36	-	-	36	-	-
Perennial	1222	882	136	560	390	17	4008	545	36	2345	345	64
Annual/Biennial	51	-	-	68	-	-	545	-	-	564	-	-
Perennial graminoid	831	51	-	407	136	-	2763	182	-	1491	109	-
Perennial forb	272	34	-	85	-	-	1018	273	9	764	82	45
Annual/biennial forb	51	-	-	68	-	-	545	-	-	564	-	-

Origin of emergence is described as S, from seed; V, from plant vegetative parts; U, unknown origin.

Table B.3. Propagule density m^{-2} for species found in donor sites upper and lower surface layer's.

	Peat						LFH					
	Upper			Lower			Upper			Lower		
Species	S	V	U	S	V	U	S	V	U	S	V	U
Grass												
Agropyron repens	-	-	-	-	-	-	-	27	-	-	-	-
Agrostis scabra	339	-	-	102	-	-	927	-	-	673	-	-
Agropyron trachycaulum	-	51	-	-	-	-	18	64	-	9	18	-
Bromus ciliatus	-	-	-	-	-	-	-	9	-	-	-	-
Calamagrostis canadensis	17	-	-	-	136	-	27	64	-	-	36	-
Unknown	-	-	17	-	-	-	-	-	-	18	18	-
Sedge												
Carex spp.	272	-	-	204	-	-	827	9	-	591	55	-
Rush												
Juncus balticus	204	-	-	102	-	-	964	9	-	218	-	-
Typha												
Typha latifolia	-	-	-	-	-	-	9	-	-	-	-	-
Forb												
Achillea millefolium	-	-	-	-	-	-	46	-	-	18	-	-
Antennaria parvifolia	-	-	-	-	-	-	-	55	-	18	9	-
Aster ciliolatus	-	-	-	-	-	-	109	-	-	9	-	-
Cornus canadensis	-	-	-	-	-	-	18	27	-	18	27	9
Crepis tectorum	-	-	-	-	-	-	173	-	-	36	-	-
Epilobium angustifolium	187	17	-	68	-	-	309	18	-	245	27	9
Epilobium ciliatum	-	-	-	-	-	-	9	-	-	9	-	-
Fragaria virginiana	-	-	-	-	-	-	36	-	-	9	-	-
Galium boreale	-	-	-	-	-	-	-	-	-	9	-	-

Table B.3. Con't.

	Peat						LFH					
	Upper			Lower			Upper			Lower		
Species	S	V	U	S	V	U	S	V	U	S	V	U
Galium triflorum	34	-	-	-	-	-	127	18	-	64	-	18
Geranium bicknellii	17	-	-	-	-	-	-	-	-	46	-	-
Petasites palmatus	-	-	-	-	-	-	55	18	-	27	9	9
Potentilla norvegica	34	-	-	68	-	-	545	-	-	518	-	-
Sonchus arvensis	17	-	-	-	-	-	36	-	-	36	-	-
Vicia americana	-	-	-	-	-	-	9	-	-	9	-	-
Viola adunca	17	-	-	-	-	-	46	-	-	55	-	-
Viola renifolia	17	-	-	17	-	-	27	-	-	55	-	-
Unknown	204	-	-	34	-	34	300	-	46	236	-	36
Woody												
Arctostaphylos uva-ursi	-	34	-	-	-	-	-	18	-	-	-	-
Betula papyrifera	17	-	-	17	-	-	55	-	-	-	-	-
Linnaea borealis	-	-	-	-	-	-	-	18	9	-	27	-
Oxycoccus microcarpus	-	356	68	17	17	17	-	-	9	-	-	-
Populus tremuloides	-	-	-	-	-	-	27	18	-	9	18	9
Potentilla tridentata	-	17	-	-	-	-	18	136	9	145	9	-
Rosa acicularis	-	-	-	-	-	-	-	9	-	-	-	-
Rubus idaeus	-	-	-	-	-	-	9	-	-	-	9	-
Symphoricarpos occidentalis	-	-	17	-	-	-	9	-	9	-	9	-
Vaccinium vitis-idaea	85	170	51	-	-	-	-	9	-	-	-	-
Unknown	-	-	-	-	-	-	9	-	-	9	-	9

Table B.3. Con't.

	Peat						LFH					
	Upper			Lower			Upper			Lower		
Species	S	V	U	S	V	U	S	V	U	S	V	U
Pteridophyte												
Athyrium filix-femina	-	-	-	-	-	-	18	-	-	46	-	-
Equisetum arvense	17	221	-	17	136	-	9	-	-	-	27	-
Equisetum scirpoides	-	17	-	17	102	-	82	18	-	27	64	-

Origin of emergence is described as S, from seed; V, from plant vegetative parts; U, unknown origin.

Table. B.4. Emergence density m^{-2} for species found in treatments soil propagule bank at the receiver site.

	LFH		Peat	
	Thick	Thin	Thick	Thin
Grass				
Agrostis scabra	62	51	148	38
Calamagrostis canadensis	14	3	16	8
Poa pratensis	-	5	5	3
Unknown	14	19	8	3
Sedge				
Carex sp.	226	127	552	209
Rush				
Juncus balticus	40	46	19	3
Juncus bufonius	3	3	-	-
Typha				
Typha latifolia	3	-	8	-
Lily				
Maianthemum canadense	3	-	-	-
Forb				
Antennaria parvifolia	3	-	-	-
Aster ciliolatus	3	-	-	-
Corydalyis aurea	-	-	3	-
Dracocephalum parviflorum	3	-	-	-
Epilobium angustifolium	3	3	8	3
Epilobium ciliatum	5	-	5	5
Fragaria virginiana	16	14	3	3
Galium boreale	-	-	-	3
Galium trifidum	3	-	-	-
Galium triflorum	3	5	-	-
Geranium bicknellii	5	5	-	-
Hieracium umbellatum	8	-	-	-
Lathyrus ochroleucus	3	5	-	-
Mertensia paniculata	5	8	-	3
Petasites palmatus	-	3	-	-
Rubus pubescens	3	-	-	-
Plantago major	3	-	-	-
Potentilla norvegica	57	27	27	14
Sonchus arvensis	-	-	5	8
Vicia americana	8	11	-	-
Viola adunca	5	3	-	-
Viola renifolia	14	3	11	-
Unknown	5	-	3	5

Table B.4. Con't.

	LFH		Peat	
	Thick	Thin	Thick	Thin
Woody				
Betula glandulosa	3	-	-	-
Ribes lacustre	3	-	-	-
Ribes oxycanthoides	3	-	-	3
Pteridophyte				
Equisetum arvense	3	3	8	-

Table B.5. Propagule density m^{-2} of plant groups from the soil propagule bank at the receiver site.

	Peat				LFH			
	Thin		Thick		Thin		Thick	
Groups	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Monocotyledon	263.7	72.2	756.0	147.1	252.9	135.3	363.2	143.6
Dicotyledon	45.7	2.7	64.6	23.3	86.1	31.7	161.4	88.8
Native grass	45.7	16.4	164.1	128.0	53.8	16.4	75.3	18.8
Introduced grass	2.7	2.7	5.4	2.7	5.4	5.4	-	-
Native forb	29.6	7.1	56.5	24.7	86.1	31.7	142.6	74.0
Introduced forb	8.1	4.7	5.4	5.4	-	-	2.7	2.7
Perennial graminoid	261.0	70.6	739.9	138.6	231.4	115.1	341.7	153.5
Annual/biennial graminoid	-	-	-	-	2.7	2.7	2.7	2.7
Perennial forb	24.2	0.0	32.3	12.3	48.4	14.0	80.7	36.4
Annual/biennial forb	13.5	5.4	29.6	13.5	32.3	24.7	61.9	33.7

SE = standard error of the mean.

Table B.6. Mean density (plants m^{-2}) of species within treatments in 2004 and 2005.

	2004				2005			
	LFH		Peat		LFH		Peat	
	Thick	Thin	Thick	Thin	Thick	Thin	Thick	Thin
Grass								
Agrostis scabra	T	0.2	T	-	1.3	0.4	0.9	0.5
Agropyron trachycaulum	0.1	0.2	-	-	0.3	0.1	T	T
Bromus ciliatus	T	T	-	-	0.2	T	-	-
Calamagrostis canadensis	1.3	0.3	0.2	T	0.4	0.2	0.2	0.1
Deschampsia cespitosa	-	-	-	-	T	-	T	T
Elymus innovatus	-	T	-	-	1.1	0.7	-	T
Hordeum jubatum	-	-	-	-	T	-	-	-
Poa palustris	-	-	-	-	T	-	-	-
Poa pratensis	-	-	-	T	0.1	T	-	-
Grass sp.	-	0.2	0.2	-	0.1	0.2	1.0	0.4
Sedge								
Carex sp.	1.3	0.4	0.3	T	3.4	1.5	12.0	6.9
Rush								
Luzula parviflora	-	-	-	-	-	-	0.3	-
Typha								
Typha latifolia	-	-	-	-	T	-	-	-
Lily								
Maianthemum canadense	-	-	0.1	-	-	-	-	-
Forb								
Achillea millefolium	T	T	-	-	0.5	0.2	T	T
Artemisia biennis	-	-	-	-	T	0.2	-	0.2
Aster ciliolatus	T	T	-	-	0.2	0.1	-	-
Aster puniceus	-	-	-	-	T	-	-	-
Atriplex subspicata	-	-	-	-	0.3	1.0	0.5	1.5
Chenopodium album	0.5	-	-	-	0.9	T	0.5	-
Circaea alpina	-	-	-	-	T	-	-	-
Cornus canadensis	-	-	-	-	T	T	-	-
Corydalyis aurea	-	-	-	-	0.1	0.2	-	-
Crepis tectorum	0.2	T	-	-	11.4	4.5	5.3	5.8
Crepis tectorum seedlings	-	-	-	-	306.8	150.4	40.7	30.7
Dicotyledon sp.	0.2	T	-	-	0.2	T	-	-
Dracocephalum parviflorum	-	-	-	-	1.1	0.5	0.2	T
Epilobium angustifolium	3.5	2.9	T	0.2	9.0	4.1	1.8	2.6
Epilobium ciliatum	-	-	-	-	3.2	0.1	0.3	0.3
Fragaria virginiana	0.6	0.6	-	T	6.5	6.8	0.2	0.3
Galium boreale	0.2	0.1	-	-	T	T	-	-

Table B.6. Con't.

	2004				2005			
	LFH		Peat		LFH		Peat	
	Thick	Thin	Thick	Thin	Thick	Thin	Thick	Thin
Galium trifidum	-	-	-	-	T	-	-	-
Galium triflorum	T	T	-	-	0.5	-	-	-
Geranium bicknellii	0.4	0.2	-	-	2.3	1.2	1.5	0.4
Hieracium umbellatum	-	-	-	-	0.2	0.1	-	-
Lathyrus ochroleucus	0.1	T	-	T	0.2	0.4	-	-
Lepidium densiflorum	-	-	-	-	0.5	-	-	T
Mertensia paniculata	0.8	0.4	-	-	0.1	0.2	-	-
Petasites palmatus	0.5	0.4	-	T	0.4	1.0	0.7	T
Plantago major	-	-	-	-	T	0.1	-	-
Portulaca oleraceae	-	-	-	-	-	T	-	-
Potentilla norvegica	1.2	0.2	T	T	1.4	0.3	1.2	0.8
Ranunculus sceleratus	-	-	-	-	-	T	T	-
Rubus pubescens	T	T	-	-	0.9	0.3	T	0.1
Salsola kali	-	-	-	-	T	0.1	-	T
Solidago canadensis	-	-	-	-	T	T	-	-
Sonchus arvensis	2.1	0.5	T	0.4	9.8	2.6	0.7	1.9
Stellaria longnifolia	-	-	-	-	0.3	0.1	-	-
Taraxacum officiniale	T	-	-	-	0.2	0.3	T	0.2
Thalaspi arvense	T	-	-	-	-	-	-	-
Trientalis borealis	T	0.1	-	-	0.7	0.3	T	T
Valeriana dioica	-	-	-	-	T	T	-	-
Vicia americana	0.3	0.2	T	T	0.8	1.0	0.2	T
Viola adunca	T	-	-	-	T	0.1	T	T
Viola renifolia	0.4	T	-	-	0.3	0.1	0.1	T
Woody								
Arctostaphylos uva-ursi	-	-	-	-	-	T	-	-
Betula glandulosa	-	-	-	-	-	-	-	T
Betula papyrifera	-	T	T	T	-	-	-	T
Cornus stolonifera	-	-	-	-	T	-	-	-
Ribes lacustre	0.1	0.1	-	-	T	0.1	-	T
Rosa acicularis	0.9	0.4	T	T	0.5	0.2	T	-
Rubus idaeus	0.8	0.3	-	-	1.0	0.2	-	T
Populus tremuloides	T	0.2	-	-	T	T	T	-
Potentilla tridentata	T	-	-	-	T	-	-	-
Salix sp.	0.4	T	0.4	0.2	-	T	0.2	0.4
Symphoricarpos occidentalis	-	T	-	-	-	-	-	-
Vaccinium myrtilloides	-	-	-	-	T	T	-	-
Woody sp.	-	-	-	-	T	-	-	-
Pteridophyte								
Equisetum arvense	0.2	T	1.0	0.2	0.6	1.4	5.2	5.6
Equisetum scirpoides	-	-	-	-	-	T	0.2	-

T, trace amounts

Table B.7. Mean percent canopy cover (per 0.1 m^{-2}) of species within treatments for 2004 and 2005 sampling period.

	2004				2005			
	LFH		Peat		LFH		Peat	
	Thick	Thin	Thick	Thin	Thick	Thin	Thick	Thin
Grass								
Agrostis scabra	T	T	T	-	0.4	0.5	0.4	0.3
Agropyron trachycaulum	T	T	-	-	0.3	T	T	T
Bromus ciliatus	T	T	-	-	0.1	0.2	-	-
Calamagrostis canadensis	0.1	T	T	T	0.7	0.1	0.1	T
Deschampsia cespitosa	-	-	-	-	T	-	T	0.1
Elymus innovatus	-	T	-	-	1.0	0.8	-	T
Hordeum jubatum	-	-	-	-	0.1	-	-	-
Poa palustris	-	-	-	-	T	-	-	-
Poa pratensis	-	-	-	T	0.1	T	-	-
Grass sp.	-	T	T	-	T	T	T	T
Sedge								
Carex sp.	0.2	T	T	T	1.1	0.6	0.6	0.4
Rush								
Luzula parviflora	-	-	-	-	-	-	T	-
Typha								
Typha latifolia	-	-	-	-	T	-	-	-
Lily								
Maianthemum canadense	-	-	T	-	-	-	-	-
Forb								
Achillea millefolium	T	T	-	-	0.8	0.3	T	T
Artemisia biennis	-	-	-	-	T	T	-	T
Aster ciliolatus	T	T	-	-	0.4	0.2	-	-
Aster puniceus	-	-	-	-	T	-	-	-
Atriplex subspicata	-	-	-	-	0.1	0.5	0.1	0.4
Chenopodium album	0.1	-	-	-	0.3	T	0.1	-
Circaea alpina	-	-	-	-	T	-	-	-
Cornus canadensis	-	-	-	-	T	T	-	-
Corydalyis aurea	-	-	-	-	0.3	0.2	-	-
Crepis tectorum	T	T	-	-	1.7	1.0	0.8	1.1
Crepis tectorum seedlings	-	-	-	-	0.9	0.4	0.1	0.1
Dicotyledon sp.	T	T	-	-	0.1	T	-	-
Dracocephalum parviflorum	-	-	-	-	0.2	0.1	0.1	T
Epilobium angustifolium	0.8	0.4	T	0.1	10.5	6.1	0.6	0.9
Epilobium ciliatum	-	-	-	-	0.2	T	T	0.1
Fragaria virginiana	0.1	0.1	-	T	1.1	1.7	0.1	0.1
Galium boreale	T	T	-	-	T	T	-	-
Galium trifidum	-	-	-	-	T	-	-	-

Table B.7. Con't.

	2004				2005			
	LFH		Peat		LFH		Peat	
	Thick	Thin	Thick	Thin	Thick	Thin	Thick	Thin
Galium triflorum	T	T	-	-	0.2	-	-	-
Geranium bicknellii	0.1	T	-	-	0.4	0.7	0.5	0.1
Hieracium umbellatum	-	-	-	-	0.2	0.1	-	-
Lathyrus ochroleucus	T	T	-	T	T	0.1	-	-
Lepidium densiflorum	-	-	-	-	0.1	-	-	T
Mertensia paniculata	0.2	0.1	-	-	0.4	0.2	-	-
Petasites palmatus	0.1	0.1	-	T	0.4	0.8	0.2	T
Plantago major	-	-	-	-	0.2	0.2	-	-
Portulaca oleraceae	-	-	-	-	-	0.1	-	-
Potentilla norvegica	0.1	T	T	T	0.9	0.4	0.3	0.3
Ranunculus sceleratus	-	-	-	-	-	T	T	-
Rubus pubescens	T	T	-	-	0.3	0.1	T	0.1
Salsola kali	-	-	-	-	T	0.1	-	T
Solidago canadensis	-	-	-	-	0.1	0.1	-	-
Sonchus arvensis	0.9	0.1	T	0.1	8.7	2.7	0.4	1.1
Stellaria longnifolia	-	-	-	-	0.1	T	-	-
Taraxacum officiniale	T	-	-	-	0.1	0.2	T	0.1
Thalaspi arvense	T	-	-	-	-	-	-	-
Trientalis borealis	T	T	-	-	0.1	0.1	T	T
Valeriana dioica	-	-	-	-	T	T	-	-
Vicia americana	T	T	T	T	0.1	0.3	0.1	T
Viola adunca	T	-	-	-	0.1	T	T	T
Viola renifolia	T	T	-	-	0.1	T	T	T
Woody								
Arctostaphylos uva-ursi	-	-	-	-	-	T	-	-
Betula glandulosa	-	-	-	-	-	-	-	0.1
Betula papyrifera	-	T	T	T	-	-	-	T
Cornus stolonifera	-	-	-	-	T	-	-	-
Ribes lacustre	0.1	T	-	-	T	0.1	-	T
Rosa acicularis	0.2	0.1	T	T	0.7	0.4	T	-
Rubus idaeus	0.1	T	-	-	2.1	0.4	-	T
Populus tremuloides	T	0.1	-	-	0.2	T	T	-
Potentilla tridentata	T	-	-	-	T	-	-	-
Salix sp.	T	T	0.1	0.1	-	T	0.1	0.4
Symphoricarpos occidentalis	-	T	-	-	-	-	-	-
Vaccinium myrtilloides	-	-	-	-	T	0.1	-	-
Woody sp.	-	-	-	-	T	-	-	-
Pteridophyte								
Equisetum arvense	T	T	T	T	0.1	0.2	0.6	0.6
Equisetum scirpoides	-	-	-	-	-	T	T	-

T, trace amounts

Table B.8. Mean soil chemical and physical parameters for the subsoil soil within each treatment in 2004 and 2005.

		2004				2005			
		LFH		Peat		LFH		Peat	
		Thick	Thin	Thick	Thin	Thick	Thin	Thick	Thin
Chemical									
Chloride	mg/L	12.24	9.71	10.14	8.24	7.38	8.14	8.71	9.29
		(4.82)	(1.41)	(1.29)	(1.20)	(0.05)	(1.61)	(0.36)	(0.72)
Calcium	mg/L	302.38	242.43	274.43	223.76	194.29	206.62	218.10	208.76
		(27.26)	(27.64)	(9.00)	(65.94)	(23.28)	(18.03)	(64.79)	(44.80)
Potassium	mg/L	6.62	5.14	4.79	4.71	3.90	4.71	5.71	3.81
		(1.20)	(0.33)	(0.28)	(0.82)	(0.60)	(0.22)	(1.36)	(0.70)
Magnesium	mg/L	95.33	76.33	86.43	66.14	54.81	53.95	58.05	55.95
		(13.11)	(8.78)	(1.86)	(16.58)	(9.53)	(4.47)	(11.44)	(8.59)
Sodium	mg/L	77.57	76.86	61.1	62.86	41.81	63.62	48.14	45.48
		(37.39)	(24.53)	(5.99)	(13.34)	(14.67)	(17.95)	(5.74)	(1.96)
Sulphate	mg/L	1190.46	969.9	1080.56	883.52	668.60	722.88	736.48	749.24
		(119.85)	(139.21)	(32.84)	(0.07)	(124.88)	(77.92)	(246.18)	(164.73)
Phosphorus	mg/kg	1.23	1.19	1.33	0.33	-	-	-	-
		(0.12)	(0.13)	(0.88)	(0.33)	-	-	-	-
TN	%	0.05	0.06	0.06	0.04	0.06	0.04	0.05	0.05
		(0.00)	(0.02)	(0.03)	(0.01)	(0.00)	(0.02)	(0.02)	(0.02)
Nitrate	mg/kg	-	-	-	-	1.59	1.57	1.67	1.58
		-	-	-	-	(0.04)	(0.07)	(0.04)	(0.07)
Ammonium	mg/kg	-	-	-	-	2.42	2.59	2.29	2.48
		-	-	-	-	(0.12)	(0.16)	(0.09)	(0.15)
OC	%	1.65	1.63	1.96	1.57	1.51	1.41	1.80	1.49
		(0.05)	(0.05)	(0.41)	(0.08)	(0.05)	(0.10)	(0.09)	(0.11)
WBOM	%	2.85	2.83	3.37	2.7	2.61	2.44	3.09	2.58
		(0.11)	(0.08)	(0.72)	(0.15)	(0.07)	(0.18)	(0.13)	(0.19)
LOIOM	%	-	-	-	-	2.33	2.24	3.19	2.76
		-	-	-	-	(0.13)	(0.24)	(1.12)	(0.27)

Table B.8. Con't.

		2004				2005			
		LFH		Peat		LFH		Peat	
		Thick	Thin	Thick	Thin	Thick	Thin	Thick	Thin
pH		7.4	7.55	7.26	7.54	7.53	7.56	7.51	7.61
		(0.06)	(0.00)	(0.08)	(0.05)	(0.04)	(0.03)	(0.08)	(0.05)
EC	sS/m	1.86	1.59	1.72	1.43	1.27	1.33	1.37	1.38
		(0.18)	(0.14)	(0.02)	(0.33)	(0.15)	(0.09)	(0.30)	(0.20)
SAR		0.99	1.09	0.91	0.98	0.70	1.07	0.87	0.80
		(0.42)	(0.30)	(0.07)	(268.21)	(0.16)	(0.28)	(0.10)	(0.08)
Physical									
Sat	%	52.14	51.38	57.29	51.33	54.90	56.52	54.24	54.19
		(1.68)	(1.20)	(5.77)	(0.47)	(0.53)	(1.11)	(3.97)	(1.39)
Sand	%	32.86	34.19	34.76	36.38	-	-	-	-
		(0.46)	(0.34)	(1.10)	(0.31)	-	-	-	-
Silt	%	31.52	31	30.48	30.52	-	-	-	-
		(0.38)	(0.62)	(0.79)	(0.50)	-	-	-	-
Clay	%	35.62	34.76	34.76	33.19	-	-	-	-
		(0.05)	(0.56)	(0.31)	(0.17)	-	-	-	-

Numbers in parentheses are standard error of the mean.
EC, electrical conductivity; SAR, sodium adsorption ratio; WB, % organic matter determined by the Walkley Black method; LOI, % organic matter determined by loss on ignition. TN, total nitrogen; OC, organic carbon; Sat, percent saturation.

Table B.9. Mean soil chemical parameters for additional surface soil parameters in each treatment in 2004 and 2005.

		2004				2005			
		LFH		Peat		LFH		Peat	
		Thick	Thin	Thick	Thin	Thick	Thin	Thick	Thin
Chemical									
Calcium	mg/L	174.57	244.05	87.57	171.17	106.46[b]	188.50[a]	90.02[b]	83.31[b]
		(13.83)	(35.94)	(12.35)	(29.68)	(9.61)	(6.19)	(18.56)	(10.71)
Magnesium	mg/L	65.52	80.31	36.86	65.12	40.17[b]	61.64[a]	37.98[b]	32.67[b]
		(1.99)	(8.57)	(6.55)	(10.93)	(4.08)	(5.11)	(7.55)	(3.98)
Sodium	mg/L	37.88	53.93	45.31	59.79	31.13	62.79	44.98	33.95
		(6.75)	(0.43)	(5.31)	(8.11)	(7.16)	(15.88)	(8.07)	(4.01)
Chloride	mg/L	23.69	24.62	20.76	18.67	14.69[a]	15.93[a]	13.86[a]	9.33[b]
		(1.11)	(3.37)	(1.88)	(2.46)	(0.35)	(1.57)	(0.57)	(0.67)
Sulphate	mg/L	408.55	692.09	280.87	600.95	249.02[b]	534.65[a]	310.33[ab]	262.52[b]
		(12.98)	(154.93)	(64.51)	(144.02)	(44.60)	(70.44)	(89.37)	(51.06)
LOIOM	%	-	-	-	-	13.34[b]	7.81[c]	21.10[a]	21.19[a]
		-	-	-	-	(0.44)	(1.08)	(1.80)	(1.41)

Numbers in parentheses are standard error of the mean.
Different letters denote significant differences between treatments at $p < 0.1$.
LOIOM, % organic matter determined by loss on ignition.

APPENDIX C. MISCELLANEOUS

Table C.1. Plant groups used in two way analysis of variance.

Plant groups	Subgroups within main groups
Morphology	
Monocotyledon	Lily, typha, graminaea, cyperaceae and juncaceae
Dicotyledon	Woody and forb
Grass	
Sedge	
Rush	
Herb	
Woody	Trees and shrubs
Pteridophyte	Horsetails and fern allies
Life history	
Perennial	Monocotyledon's, dicotyledon and pteridophytes
Annual/biennial	Monocotyledon's and dicotyledon
Perennial forb	
Perennial grass	
Annual/biennial grass	
Annua/biennial forb	
Origin	
Native	
Grass	
Forb	
Introduced	
Grass	
Forb	

Table C.2. Plant species characteristics.

Species	Common Name	Family	Growth Form	Life form	Origin
Athyrium filix-femina Roth (L.)	Fern	Polypodiacea	Fern	Perennial	Native
Agropyron repens (L.) Beauv.	Quack grass	Triticeae	Grass	Perennial	Introduced
Agropyron trachycaulum (Link) Malte.	Slender wheat grass	Triticeae	Grass	Perennial	Native
Agrostis scabra Willd.	Tickle grass	Aveneae	Grass	Perennial	Native
Beckmannia syzigachne (Steud) Fern.	Slough grass	Beckmannia	Grass	Annual	Native
Bromus ciliatus L.	Fringed brome	Aveneae	Grass	Perennial	Native
Bromus inermis Leyss.	Smooth brome	Aveneae	Grass	Perennial	Introduced
Calamagrostis canadensis (Michx) Beauv.	Marsh reed grass	Aveneae	Grass	Perennial	Native
Deschampsia cespitosa (L.) Beauv.	Tufted hair grass	Graminaea	Grass	Perennial	Native
Elymus innovatus Beal.	Hairy wild rye	Triticeae	Grass	Perennial	Native
Hordeum jubatum L.	Foxtail barley	Gramineae	Grass	Perennial	Native
Poa palustris L.	Fowl blue grass	Graminaea	Grass	Perennial	Native
Poa pratensis L.	Kentucky blue grass	Festuceae	Grass	Perennial	Introduced
Achillea millefolium L.	Common yarrow	Asteraceae	Herb	Perennial	Native
Achillea sibirica Ledeb	Siberian yarrow	Asteraceae	Herb	Perennial	Native
Antennaria parvifolia Nutt.	Small-leaved Everlasting	Asteraceae	Herb	Perennial	Native
Arnica cordifolia Hook.	Heart-leaved arnica	Asteraceae	Herb	Perennial	Native
Artemisia biennis Willd.	Biennial Sagewort	Asteraceae	Herb	Annual/Biennial	Native
Aster ciliolatus Lindl.	Lindley's Aster	Asteraceae	Herb	Perennial	Native
Aster conspicuus Lindl.	Showy Aster	Asteraceae	Herb	Perennial	Native
Atriplex subspicata (Nutt.) Rydb.	Salt rush	Chenopodiaceae	Herb	Annual	Native
Chenopodium album L.	Lamb's quarters	Chenopodiaceae	Herb	Annual	Introduced
Chenopodium capitatum (L.) Aschers.	Strawberry blite	Chenopodiaceae	Herb	Annual	Native
Circaea alpina L.	Enchanter's nightshade	Ongraceae	Herb	Perennial	Native
Cirsium arvense (L.) Scop.	Canada thistle	Asteraceae	Herb	Perennial	Introduced
Cornus canadensis L.	Bunchberry	Umbelliferae	Herb	Perennial	Native
Corydalyis aurea Willd.	Golden corydalis	Papaveraceae	Herb	Annual/Biennial	Native
Corydalyis sempervirens (L.) Pers.	Pink corydalis	Papaveraceae	Herb	Annual/Biennial	Native
Crepis tectorum L.	Annual hawksbeard	Asteraceae	Herb	Annual	Introduced
Dracocephalum parviflorum Nutt.	American dragon head	Labiatae	Herb	Annual/Biennial	Native
Epilobium angustifolium L.	Fireweed	Ongraceae	Herb	Perennial	Native
Epilobium ciliatum Raf.	Northern willow-herb	Ongraceae	Herb	Perennial	Native

Table C.2. Con't.

Species	Common Name	Family	Growth Form	Life form	Origin
Fragaria virginiana Duchesne	Purple-stemmed Aster	Asteraceae	Herb	Perennial	Native
Galeopsis tetrahit L.	Hemp nettle	Labiate	Herb	Annual	Introduced
Galium boreale L.	Northern bedstraw	Rubiaceae	Herb	Perennial	Native
Galium trifidum L.	Small bedstraw	Rubiaceae	Herb	Perennial	Native
Galium triflorum Michx.	Sweet bedstraw	Rubiaceae	Herb	Perennial	Native
Geranium bicknellii Britt.	Bicknell's geranium	Geraniaceae	Herb	Annual/Biennial	Native
Hieracium umbellatum L.	Narrow-leaved hawkweed	Asteraceae	Herb	Perennial	Native
Lathyrus ochroleucus Hook.	Creamy pea-vine	Fabaceae	Herb	Perennial	Native
Lepidium densiflorum Schrad.	Common pepper grass	Cruciferae	Herb	Annual	Native
Maianthemum canadense Desf.	Wild lily-of-the-valley	Liliaceae	Lily	Perennial	Native
Melilotus alba Desr.	White sweet clover	Fabaceae	Herb	Biennial	Introduced
Melilotus officinalis (L.) Lam.	Yellow sweet clover	Fabaceae	Herb	Biennial	Introduced
Mertensia paniculata (Ait) G. Don.	Tall lungwort	Boraginaceae	Herb	Perennial	Native
Petasites palmatus (Ait) A. Gray	Palmate-leaved coltsfoot	Asteraceae	Herb	Perennial	Native
Petasites sagittatus (Pursh) A. Gray	Arrow-leaved coltsfoot	Asteraceae	Herb	Perennial	Native
Plantago major L.	Common plantain	Plantaginaceae	Herb	Perennial	Introduced
Polygonum lapifolium L.	Green smartweed	Polygonaceae	Herb	Annual	Native
Portulaca oleraceae L.	Purslane	Portulacaceae	Herb	Annual	Introduced
Potentilla norvegica L.	Rough cinquefoil	Rosaceae	Herb	Annual/Biennial	Native
Potentilla tridentata Ait.	Three-leaved cinquefoil	Rosaceae	Herb	Perennial	Native
Pyrola asarifolia Michx.	Common pink wintergreen	Pyrolaceae	Herb	Perennial	Native
Ranunculus sceleratus L.	Celery-leaved buttercup	Ranunculaceae	Herb	Annual	Native
Rhinanthus borealis (Sterneck) Chab.	Rattle box	Schopjulariaceae	Herb	Annual	Native
Rubus chamaemorus L.	Cloudberry	Rosaceae	Herb	Perennial	Native
Rubus pubescens Raf.	Dewberry	Rosaceae	Herb	Perennial	Native
Rumex occidentalis S. Wats.	Western dock	Polygonaceae	Herb	Perennial	Native
Salsola kali L.	Russian thistle	Chenopodiaceae	Herb	Annual	Native
*Solidago canadensis*L.	Goldenrod	Asteraceae	Herb	Perennial	Native
Sonchus arvensis L.	Perennial sow thistle	Asteraceae	Herb	Perennial	Introduced
Stellaria longnifolia Muhl.	Long-leaved chickweed	Caryophyllaceae	Herb	Perennial	Native
Taraxacum officiniale Weber	Common dandelion	Asteraceae	Herb	Perennial	Introduced
Thalictrum venulosum Trel.	Veiny meadow rue	Ranunculaceae	Herb	Perennial	Native

Table C.2. Con't.

Species	Common Name	Family	Growth form	Life form	Origin
Trientalis borealis Raf.	Northern starflower	Primulaceae	Herb	Perennial	Native
Triglochin palustris sL.	Slender arrow grass	Juncaginacea	Herb	Perennial	Native
Typha latifolia L.	Common cattail	Taxus	Herb	Perennial	Native
Urtica dioica L.	Stinging nettle	Cannabinaceae	Herb	Perennial	native
Valeriana dioica L.	Valerian	Valerianaceae	Herb	Perennial	Native
Vicia americana Muhl.	American vetch	Fabaceae	Herb	Perennial	Native
Viola adunca J.E. Smith	Early blue violet	Violaceae	Herb	Perennial	Native
Viola renifolia A. Gray	Kidney-leaved violet	Violaceae	Herb	Perennial	Native
Equisetum arvense L.	Field horsetail	Equisetaceae	Horsetail	Perennial	Native
Equisetum scirpoides Michx.	Scouring rush	Equisetaceae	Horsetail	Perennial	Native
Luzula parviflora (Ehrh.) Desv.	Wood rush	Juncaceae	Juncus	Perennial	Native
Maianthemum canadense Desf.	Wild lily-of-the-valley	Liliaceae	Lilly	Perennial	Native
Juncus balticus Willd.	Wire rush	Juncaceae	Rush	Perennial	Native
Juncus bufonius L.	Toad rush	Juncaceae	Rush	Annual	Native
Carex sp.	Sedge	Cyperaceae	Sedge	Perennial	Native
Alnus crispa (Ait.) Pursh	Green alder	Betualaceae	Shrub	Perennial	Native
Amelanchier alnifolia (Nutt.)	Saskatoon berry	Rosaceae	Shrub	Perennial	Native
Arctostaphylos uva-ursi (L.) Spreng.	Kinnikinnick	Ericaceae	Shrub	Perennial	Native
Betula glandulosa Michx.	Dwarf birch	Betualaceae	Shrub	Perennial	Native
Cornus stolonifera Michx.	Red-osier dogwood	Cornaceae	Shrub	Perennial	Native
Ledum groenlandicum Oeder	Common labrador tea	Ericaceae	Shrub	Perennial	Native
Linnaea borealis L.	Twin flower	Ericaceae	Shrub	Perennial	Native
Potentilla fructicosa L.	Shrubby cinquefoil	Rosaceae	Shrub	Perennial	Native
Ribes lacustre (Pers.) Poir.	Bristly black current	Grossulariaceae	Shrub	Perennial	Native
Ribes oxycanthoides L.	Wild gooseberry	Grossulariaceae	Shrub	Perennial	Native
Ribes triste Pall.	Wild red currant	Grossulariaceae	Shrub	Perennial	Native
Rosa acicularis Lindl.	Prickly rose	Rosaceae	Shrub	Perennial	Native
Rubus idaeus L.	Wild red raspberry	Rosaceae	Shrub	Perennial	Native
Salix sp.	Willow	Salicaceae	Shrub	Perennial	Native
Sheperdia canadensis (L.) Nutt.	Canadian buffalo-berry	Elaeagnaceae	Shrub	Perennial	Native
Symphoricarpos occidentalis Hook.	Buckbrush	Caprifoliacea	Shrub	Perennial	Native
Vaccinium myrtilloides Michx.	Blueberry	Ericaceae	Shrub	Perennial	Native
Vaccinium myrtillus L.	Small bog cranberry	Ericaceae	Shrub	Evergreen	Native

Table C.2. Con't.

Species	Common Name	Family	Growth form	Life form	Origin
Vaccinium vitis-idaea L.	Bog cranberry	Ericaceae	Shrub	Evergreen	Native
Betula papyrifera Marsh.	White birch	Betualaceae	Tree	Perennial	Native
Picea mariana (Mill.) BSP.	Black spruce	Pinaceae	Tree	Perennial	Native
Populus balsamifera L.	Balsam poplar	Salicaceae	Tree	Perennial	Native
Populus tremuloides Michx.	Trembling aspen	Salicaceae	Tree	Perennial	Native

Table C.3. Presence (+) / absence (-) of species for above ground vegetation and propagules found at donor site and propagules found at receiver site.

	Peat				LFH			
	Donor site		Receiver site		Donor site		Receiver site	
Species	V	PB	Thin PB	Thick PB	V	PB	Thin PB	Thick PB
Grasses								
Agropyron repens	-	-	-	-	-	+	-	-
Agrostis scabra	+	+	+	+	+	+	+	+
Agropyron trachycaulum	-	+	-	-	-	+	-	-
Bromus ciliatus	-	-	-	-	-	+	-	-
Calamagrostis canadensis	+	+	+	+	+	+	+	+
Poa pratensis	-	-	+	+	-	-	+	-
Sedges								
Carex spp.	+	+	+	+	+	+	+	+
Rushes								
Juncus balticus	-	+	+	+	+	+	+	+
Juncus bufonius	-	-	-	-	-	-	+	+
Typha								
Typha latifolia	-	-	-	+	-	+	-	+
Lily								
Maianthemum canadense	+	-	-	-	-	-	-	+
Forbs								
Achillea millefolium	+	-	-	-	+	+	-	-
Antennaria parvifolia	-	-	-	-	-	+	-	+
Aster ciliolatus	+	-	-	-	+	+	-	+
Cornus canadensis	+	-	-	-	+	+	-	-
Corydalyis aurea	-	-	-	+	-	-	-	-
Valeriana dioica	-	-	-	-	-	+	-	-
Dracocephalum parviflorum	-	-	-	-	-	-	-	+
Epilobium angustifolium	+	+	+	+	+	+	+	+
Epilobium ciliatum	-	-	+	+	-	+	-	+
Fragaria virginiana	+	-	+	+	+	+	+	+
Galium boreale	+	-	+	-	+	+	-	-
Galium trifidum	-	-	-	-	-	-	-	+
Galium triflorum	-	+	-	-	+	+	+	+
Geranium bicknellii	-	+	-	-	+	+	+	+
Hieracium umbellatum	-	-	-	-	-	-	-	+
Lathyrus ochroleucus	-	-	-	-	-	-	+	+
Mertensia paniculata	+	-	+	-	+	-	+	+
Petasites palmatus	+	-	-	-	+	+	+	-
Plantago major	-	-	-	-	-	-	-	+
Potentilla norvegica	-	+	+	+	-	+	+	+
Pyrola asarifolia	-	-	-	-	+	-	-	-
Ranunculaceae macounii	-	-	-	-	+	-	-	-
Rubus chamaemorus	+	-	-	-	+	-	-	-
Rubus pubescens	+	-	-	-	+	-	-	+
Sonchus arvensis	-	+	+	+	+	+	-	-

Table C.3. Con't.

	Peat				LFH			
	Donor site		Receiver site		Donor site		Receiver site	
			Thin	Thick			Thin	Thick
Species	V	PB	PB	PB	V	PB	PB	PB
Taraxacum officiniale	-	-	-	-	+	-	-	-
Vicia americana	-	-	-	-	+	+	+	+
Viola adunca	-	+	-	-	-	+	+	+
Viola renifolia	-	+	-	+	-	+	+	+
Woody								
Alnus crispa	+	-	-	-	+	-	-	-
Arctostaphylos uva-ursi	+	+	-	-	+	+	-	-
Betula glandulosa	+	-	-	-	-	-	-	+
Betula papyrifera	-	+	-	-	-	+	-	-
Ledum groenlandicum	+	-	-	-	+	-	-	-
Linnaea borealis	-	-	-	-	+	+	-	-
Picea mariana	+	-	-	-	-	-	-	-
Populus balsamifera	-	-	-	-	+	-	-	-
Populus tremuloides	+	-	-	-	+	+	-	-
Potentilla fructicosa	-	-	-	-	+	-	-	-
Potentilla tridentata	-	+	-	-	+	+	-	-
Ribes lacustre	-	-	-	-	-	-	-	+
Ribes oxycanthoides	-	-	+	-	+	-	-	+
Rosa acicularis	+	-	-	-	+	+	-	-
Rubus idaeus	-	-	-	-	-	+	-	-
Salix sp.	+	-	-	-	+	-	-	-
Sheperdia canadensis	-	-	-	-	+	-	-	-
Symphoricarpos occidentalis	+	+	-	-	+	+	-	-
Vaccinium myrtillus	+	+	-	-	-	+	-	-
Vaccinium vitis-idaea	+	+	-	-	+	+	-	-
Pteridophyte								
Athyrium filix-femina	-	-	-	-	-	+	-	-
Equisetum arvense	+	+	-	+	+	+	+	+
Equisetum scirpoides	-	+	-	-	-	+	-	-

V, above ground vegetation; PB, Soil propagule bank.

Table C.4. Mean soil chemical values for donor sites by depth interval.

		pH	EC dS m^{-1}	Nitrate mg/kg	Phosphorus mg/kg	Potassium mg/kg	Sulphate mg/kg	IC %	TOC %	TC %
Peat	0-10 cm	5.24	0.46	18.87	33.29	723.29	159.57	0.21	31.29	31.50
		(0.24)	(0.07)	(3.83)	(11.68)	(179.94)	(52.58)	(0.06)	(4.94)	(4.91)
	10-30 cm	4.93	0.32	29.43	17.75	642.25	201.50	0.18	31.78	31.95
		(0.25)	(0.25)	(9.87)	(6.16)	(187.03)	(80.59)	(0.003)	(10.29)	(10.3)
LFH	0-10 cm	5.88	0.49	5.98	5.58	254.00	28.25	0.21	12.02	12.22
		(0.14)	(0.04)	(1.37)	(1.82)	(68.8)	(5.89)	(0.05)	(3.46)	(3.48)
	10-30 cm	5.74	0.31	2.62	1.20	59.00	12.20	0.13	0.78	0.88
		(0.19)	(0.19)	(0.19)	(0.19)	(0.19)	(0.19)	(0.19)	(0.19)	(0.19)

Peat 0 to 10 cm n = 7; Peat 10 to 30 cm n = 4

LFH 0 to 10 cm n = 11; LFH 10 to 30 cm = 5

Numbers in parentheses are standard error of the mean.

IC, Inorganic carbon; TOC, total organic carbon; TC, total carbon

Table C.5. Climate data from W1 weather station for 2004 and 2005 field season.

	Apr	May	Jun	Jul	Aug	Sep
2004						
Minimum air temp (°C)					7.5	3.6
Maximum air temp (°C)					18.7	13.1
Average air temp (°C)					13.0	8.2
Minimum wind speed (m/s)					0.2	0.6
Maximum wind speed m/s					7.1	8.9
Average wind speed (m/s)					2.6	3.6
Average total precip (mm)					0.7	2.6
Cummulative precip (mm)						
Total net radiation (MJ/m^2)					6.7	3.4
2005						
Minimum air temp (°C)	0.3	3.5	8.5	11.0	9.2	4.7
Maximum air temp (°C)	11.2	16.9	20.1	22.5	19.8	15.6
Average air temp (°C)	5.5	10.3	14.4	16.5	14.2	9.6
Minimum wind speed (m/s)	0.6	0.4	0.3	0.3	0.4	0.2
Maximum wind speed m/s	9.8	8.9	7.9	8.3	8.5	7.2
Average wind speed (m/s)	3.9	3.4	2.9	2.9	3.1	2.7
Average total precip (mm)	0.0	1.0	2.4	4.3	2.3	0.3
Cumulative precip (mm)	0.3	30.7	71.9	131.1	64.5	9.9
Total net radiation ($MJ\ m^{-2}$)	10.7	12.9	11.8	12.5	8.8	4.4