University of Alberta

OIL SANDS MINE RECLAMATION USING BOREAL FOREST SURFACE SOIL (LFH) IN NORTHERN ALBERTA

by

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Dedicated to my son, George Dean MacKenzie

ABSTRACT

A major barrier to reclamation after oil sands mining is lack of commercially available, diverse native plant seeds and propagules for revegetation. Potential of LFH (forest floor material) developed on coarse textured soil for establishing native plants and how salvage, placement and storage affect plant establishment and soils were studied. Abundance and composition of vascular plants in the soil propagule bank were determined in a growth chamber. In large field experiments, LFH salvage (10, 25 cm) and placement (10, 20 cm) depths were compared to standard peat-mineral mix used in oil sands reclamation. On a smaller scale, LFH developed from fine and coarse textured soil was salvaged (10, 30, 60 cm) and replaced (2, 5, 10 cm) on mineral and peat-mineral mix substrates. Storage effects were determined on soil chemical and physical properties, seed germination and viability, root viability and plant emergence, considering length of stockpiling, stockpile size, construction season and soil texture. Effects of plant derived smoke water and potassium nitrate on germination of cold stratified and non stratified seed from 18 native boreal plant species were determined in a growth chamber.

LFH placement increased species richness, density and canopy cover of total, native, woody, herbaceous and non native plant species on most substrates. Shallow salvaged LFH resulted in greater species richness, canopy cover and plant density than deeper salvaged LFH. Greater placement depths resulted in increased canopy cover. Stockpiling LFH resulted in a significant decline (up to 100 %) in seed viability for 24 of 27 boreal species in small and large stockpiles at depths below 1.0 m. Anaerobic soil conditions developed soon after

construction and persisted below 1.0 m in large stockpiles; anaerobic conditions developed in smaller stockpiles. Native boreal plant seeds responded to smoke water and potassium nitrate. *Vaccinium myrtilloides* had the largest increased germination using smoke water, and the most reduced germination using potassium nitrate. LFH conservation is critical for development of diverse, self-sustaining forested ecosystems on mined lands. Direct placement is better than stockpiling because seed viability, nutrients, organic matter and soil biota are difficult and costly to replenish once degradation occurs in stockpiles.

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CHAPTER I
OIL SANDS MINE RECLAMATION USING BOREAL FOREST SURFACE SOIL (LFH) IN NORTHERN ALBERTA: INTRODUCTION

1.1 BACKGROUND

In the mineable oil sands region of northeastern Alberta the bitumen bearing McMurray formation occurs close enough to the ground surface to be extracted by open pit mining using shovels and trucks. Surface mining leaves a reconstructed landscape of overburden dumps and consolidated tailings deposits. Oil sands mining in northeastern Alberta has disturbed approximately 715 km^2 (71,500 ha) of the 4,800 km^2 of land available for mining (Alberta Environment 2012). The number of projects and total extent of disturbance continue to increase.

Current regulations require that disturbances be reclaimed to diverse, self-sustaining boreal forest communities similar to those in the surrounding region (Alberta Environment 2010). The majority of mined lands were formerly peatlands but are generally reclaimed to upland forests (Mackenzie and Naeth 2010). Reclaimed forests are quite different from reference or undisturbed upland plant communities, especially the understory.

Oil sands operators have recently begun salvaging LFH for cover soil. LFH is an important material for improving reclamation of upland landscapes because it can provide an important and unique source of seed, nutrients, organic matter, vegetative propagules, macro invertebrates, meso fauna, microorganisms and woody debris (Brown 2010, MacKenzie and Naeth 2010). Its limited availability in the mineable oil sands region means operators must optimize its use across post-disturbed landscapes, as there is no other economical, alternative source of native boreal propagules that can supply such diversity and abundance of species.

Research outside the oil sands region has determined how topsoil handling practices affect soil quality, plant establishment and seed longevity; however, little research addresses how changes in salvage depth and placement depth of

LFH affect reestablishment of native plant species and soil quality, and how storage of LFH affects soil quality and viability of seeds and vegetative propagules. Understanding how different soil handling practices and addition of amendments influence plant establishment and soil quality are needed to make better informed decisions for conservation and reclamation in the oil sands.

1.2 LFH DEFINITION

The Soil Classification Working Group in Canada (1998) provides a definition of the LFH layer or horizon, generally used in soil science. Organic soil horizons, (L, F, H) develop primarily from accumulation of leaves, twigs and woody materials with or without a minor component of mosses, and are normally associated with upland forest soils with imperfect drainage or drier. L horizon is characterized by accumulation of organic matter with original structures easily discernible. F horizon is characterized by accumulation of partially decomposed organic matter; some original structures are difficult to recognize. Material can be partly comminuted by soil fauna (moder) or partly decomposed and permeated by fungal hyphae (mor). H horizon is characterized by accumulated decomposed organic matter with original structures indiscernible. H horizon has greater humification than F, mainly due to actions of organisms. It is frequently intermixed with mineral grains, especially near mineral horizon junctions.

In the Cumulative Environmental Management Association (CEMA) Guidelines for Reclamation to Forest Vegetation in the Athabasca Oil Sands Region (Alberta Environment 2010), the term LFH is used for forest floor materials accumulated on mineral surface soil under upland forest. The term upland surface soils is used for shallow salvaged materials consisting of LFH layers and upper 10 to 30 cm of underlying mineral soils (LFH layers plus A horizon). The term LFH amendment is used for salvaged upland surface soil material for reclamation capping or cover.

Many government approvals use the term, upland surface soil, to refer to LFH mineral mixes. For example, definitions used in the Total 2011 approval appear representative of the current government approach (Alberta Environment 2011).

LFH refers to the forest floor that accumulates on the mineral soil surface under forest vegetation, which includes litter and unincorporated humus. Upland soil refers to mineral soils developed on mineral material under forest in locations with imperfect drainage or drier, typically including LFH and A, B and C horizons. Upland surface soil refers to a stratum salvaged from an upland soil that includes the LFH, A horizon, and in some cases part or all of the B horizon.

There are numerous definitions for LFH or forest floor material as reclamation materials, in academia, industry and government. Some common terms are LFH, forest floor material, LFH mineral mix, forest floor mineral mix, LFH and shallow mineral horizons, forest litter, litter, LFH topsoil, upland surface soil, forest floor mineral mix. Topsoil is commonly used for surface soils in other parts of the world. This plethora of terms can cause considerable confusion.

In this dissertation, the term LFH refers to organic material from an upland forest and describes the mix of LFH layer and upper mineral soil, which can include the Ahe, Ae, upper B horizon or combinations of these horizons, over stripped during salvage and placed for reclamation in the oil sands region. The term LFH layer is the same as the definition provided by the Soil Classification Working Group in Canada and is used to reference the organic layers present in a natural or naturally disturbed forest. The actual terms used by the authors of publications cited within the dissertation will be reported, wherever possible.

1.3 LFH USED FOR RECLAMATION

Conservation of forest topsoil is critical for development of self-sustaining forested ecosystems on post-mined land. Topsoil provides an important source of native plant genetic material. Other properties of topsoil that make it a superior reclamation material to overburden, organic substitutes or amendments include nutrients, microbial populations, higher organic matter content, better structure and aeration, and lower resistance to root penetration and water infiltration (Power et al. 1979). The LFH layer is essential for maintenance of nutrient cycles and productive forests (Fisher and Binkley 2000). LFH contains an abundant

source of macro and micro nutrients and provides a rich source of organic matter, plant propagules, microbial biomass and soil fauna (McMillan 2005, Battigelli 2006, MacKenzie 2006, Brown 2010).

The role of forest topsoil as a source of native plant seeds and vegetative propagules on mined lands has long been recognized. On mines in alpine, subtropical and temperate forests, salvaging forest topsoil improved reclamation of diverse, self-sustaining and productive plant communities (Tacey and Glossop 1980, Smyth 1997, Hall et al. 2010). In northeastern Alberta in the Athabasca Oil Sands Region, the importance of salvaging LFH has been recognized. However, in the past, both perceived and actual logistics and cost prevented use of salvaged LFH as a reclamation material on a large scale (Ziemkiewicz et al. 1980).

1.4 SALVAGE AND PLACEMENT DEPTH

Plant establishment from donor soil is largely dependent on salvage depth. Shallow salvage depth (10 cm) results in faster recruitment of native plants from in situ seeds than does deeper (30 cm) salvage (Rokich et al. 2000). LFH contains an abundant and diverse source of seed and plant propagules, collectively known as propagules (Rydgren and Hestmark 1997, Qi and Scarratt 1998, Rydgren et al. 2004, MacKenzie and Naeth 2010). Most propagules in forest surface soils are in the upper organic layer and upper cm of mineral soil (Strong and La Roi 1983, Whittle et al. 1998). Propagule abundance naturally decreases with depth, therefore when used as a donor material, deep salvage would dilute propagule abundance. Soil nutrients and organic matter also vary with depth. The LFH layer contains more organic matter, available nutrients and cation exchange sites than mineral horizons below (Huang and Schoenau 1996, Arocena and Sanborn 1999). Shallow salvage creates a reclaimed surface soil with higher organic carbon, total nitrogen and mineralizable nitrogen than deeper salvage (Schwenke et al. 1999).

Propagule abundance naturally decreases with increasing soil depth; however, placement of donor material can result in variable propagule distribution (Koch et al. 1996). After donor materials are placed on reclamation areas, propagules

buried at depths greater than 5 to 10 cm may not successfully emerge (Grant et al. 1996). If plant vegetative parts, such as rhizomes, are buried too deep, emergence is reduced. Soil texture influences the depth from which seeds or vegetative propagules can emerge. For example, Bevenuti (2003) concluded emergence of *Datura stramonium* L. (jimsonweed) was negatively affected by burial depth, which was more detrimental in fine textured than in coarse textured soils.

Most studies assessing donor materials as seed sources concluded shallow placement (10 cm) of topsoil resulted in similar species establishment to deep (30 cm) placement (Holmes et al. 2000, Rokich et al. 2000). However, deep placement resulted in greater plant cover and biomass (Mcinnies and Nicolas 1980, Bowen et al. 2005, Schladweiler et al. 2005). Deeply buried propagules can lie dormant for years and lose viability or emerge but never establish due to low carbohydrate reserves (Batson 1998, Benvenuti 2003). In shallow placed LFH, propagules can emerge but available water and nutrients can limit establishment.

Application of donor materials on a suitable substrate is important as substrate provides the environment in which roots physically stabilize plants and extract water and nutrients. Several substrates are available in the Alberta Oil Sands Region, including clay textured parent material (mineral soil) and sand textured parent material (mineral soil) or a mix of mineral soil and peat. Substrates will differ, for example, in water holding capacity, temperature, nutrient availability.

1.5 STOCKPILING

During mining soil and LFH must be stored, usually in stockpiles, for variable periods of time, depending on available areas requiring reclamation. Negative impacts of storage and storage time on soil physical and chemical properties have been documented (Dougal 1950, Widdowson et al. 1982, Abul-Kareem and McRae 1984, Stark and Redente 1987). Over time, stockpiles become anaerobic below the surface, negatively affecting biological properties (Abdul-Kareem and McRae 1984). Stockpiling reduces total and available nitrogen and organic carbon (Visser et al. 1984, Harris and Birch 1987, Kundu and Ghose 1997) and

significantly reduces mycorrhizae and other microbial populations (Harris et al. 1989). Anaerobic conditions are more prevalent with depth and fine textured soils (Abul-Kareem and McRae 1984). Stockpiled soil becomes biologically stagnant for aerobic microorganisms, seeds, roots; there is little evidence soils stockpiled in cool climates are stagnant in nutrients. Seed viability losses can occur in a short time (Rokich et al. 2000), with various factors affecting seed longevity. Seeds can be lost through in situ germination, microbial pathogens and natural senescence (Harris and Birch 1987); seeds and roots can be physically damaged.

1.6 GERMINATION CUES

Frequent disturbances in the boreal forest cue seed germination enhancement. Gaps created from disturbances change the once stable environment through increases in soil temperature, light transmittance and soil nitrogen (Bonan and Shugart 1989). The stimulatory effects of nitrate on seed germination are well known; however, few studies have evaluated native boreal shrubs and herbaceous plants (Toole et al. 1956). Calcium nitrate applied at a rate of 336 kg ha^{-1} to mature *Abies balsamea* (L.) Mill. (balsam fir) *Picea mariana* (Mill.) BSP (black spruce) stands, increased *Rubus idaeus* L. (red raspberry) emergence by 75 plants per 25 m^{-2} relative to no fertilizer applied (Jobidon 1993). Auchmoody (1979) assessed response of *Prunus pensylvanica* L. (pin cherry) emergence in a 60 year old Allegheny hard wood forest using several sources of nitrogen fertilizers. The no fertilizer treatment resulted in zero emergence, while with nitrogen fertilizer, after the second growing season, there were 272,000 to 675,000 seedlings ha^{-1}.

Studies have addressed enhancing germination with specific seed treatments. For example, stimulated germination from plant derived smoke was first reported by De Lange and Boucher (1993). Other studies have since documented over 170 native Australian species from 37 families with enhanced germination from smoke (Roche et al. 1997, Bell 1999). Stimulatory effects of smoke are not limited to species in fire prone environments; germination has been stimulated in *Lactuca* L. (lettuce) (Drewes et al. 1995), *Apium graveolens* L. (celery) (Thomas

and Van Staden 1995) and several biotypes of *Avena fatua* L. (wild oats) (Adkins and Peters 2001), including one from Canada. There is no record of using plant derived smoke to enhance seed germination in the boreal forest.

1.7 RESEARCH OUTLINE AND OBJECTIVES

This research was designed to assess the potential of LFH developed on coarse textured soil (sand) for establishing native boreal plant species and to determine how various salvage, placement and storage practices affect native plant establishment and soil quality in the oil sands region. Most donor soil transfer and stockpile studies have been conducted in subtropical, temperate and arid regions, with research in the boreal forest being very limited (Lanoue and Qualizza 2001, Brown 2010, MacKenzie and Naeth 2010). The majority of the research conducted in the boreal forest has a narrow focus that does not address effects of salvage depth, placement depth or type of substrate and the possible interactions. Few studies have assessed effects of burial depth, soil texture and water content on plant emergence from rhizomes. No studies evaluated effects of stockpiling on soil chemical properties and buried in situ seeds in the boreal forest. Research has not addressed if plant derived smoke enhances seed germination in boreal forest vascular plants. Few studies evaluated interactions of plant derived smoke and potassium nitrate. Thus a series of experiments were conducted across multiple scales in the field and growth chamber to enhance the knowledge base for what factors affect native plant establishment and soil quality, and to aid in developing better operational practices that optimize LFH for oil sands reclamation.

Research was conducted to determine effectiveness of LFH salvaged from coarse textured soils in providing an alternative cover soil and in situ propagules for vegetation establishment to the commonly used peat-mineral mix. Large experimental plots were established using standard mine equipment and LFH from upland xeric (*Pinus banksiana* Lamb. (jack pine) forest developed on coarse textured soils) and submesic ecosites (*Pinus banksiana* and *Populus tremuloides* Michx. (trembling aspen) mixed forest developed on coarse textured soils)

classified according to Beckingham and Archibald (1996). Effects of LFH salvage depth, LFH placement depth and substrate type on plant establishment, propagule distribution and soil properties were evaluated. The soil propagule bank, plant community and soil chemical properties were assessed prior to salvage and over three growing seasons after placement in the field. The growth chamber experiments are described in Chapter 2 and the field experiments in Chapter 3.

Initial results from the large plot experiments were used to develop experiments that focused on controlled salvage and placement depths using LFH developed on coarse and fine textured soil, placed on different substrates available in the oil sands region. These results showed salvage depth and placement depth affected reestablishment of native plant species and influenced soil chemical properties that could impact plant growth. Large size equipment used to salvage and place LFH resulted in highly variable salvage and placement depths, and likely contributed to interactions between salvage and placement depth that would otherwise be unexpected for some response variables such as canopy cover. The large experimental units and limited placement area prevented complete separation of effects of donor LFH from xeric and submesic ecosites on each substrate. Controlled experiments were thus used to further determine effects of soil salvage and soil placement depths using LFH from different ecosites on different substrates commonly found in the oil sands region. Experimental plots were established by hand to aid in more control over LFH selection, which large mine equipment could not do. This experiment is detailed in Chapter 4.

The majority of native plants establishing from donor LFH emerge from in situ seeds and roots. Results from Chapter 4 were unexpected, with few plants establishing during the first growing season using shallow placement. Responses were likely affected by different soil textures and variable soil water contents caused by different aspects, slopes and substrates. A common trend in all LFH research was that the first plants to emerge typically originated from vegetative propagules. To further control experimental error and determine how placement depth affected plant establishment from roots under a range of environmental conditions, a greenhouse experiment was conducted. The research to determine

effects of burial depth, soil texture and soil water on plant emergence from roots from various native boreal plant species is described in Chapter 6.

Initial results from research described in Chapters 2 and 3 and from previous research conducted by Mackenzie and Naeth (2010) showed LFH was an extremely effective method for revegetation in the oil sands region. Considering oil sands operators often stockpile LFH led to further research about how various stockpiling methods would affect longevity of viable propagules and soil quality. The uniqueness of this experiment from other stockpile research was the design and monitoring. Historical stockpile studies assessed topsoil storage from either controlled small storage piles or historical large storage piles with unknown origin of materials. Large operational size stockpiles had only the upper 1 to 3 m assessed, leaving the remainder of the stockpiled material uninvestigated. This experiment assessed effects of storage time, storage depth and stockpile size on viability and germination of various boreal seeds and roots and on resulting soil chemical and physical properties and is detailed in Chapter 5.

Smoke water derived from burnt vegetation has improved germination of many native species established in fire and non fire prone ecosystems outside of the boreal forest. Nitrate has also had stimulatory effects. Research has not addressed if plant derived smoke enhances seed germination in boreal forest vascular plants. Few studies evaluated interactions of plant derived smoke and potassium nitrate. Research from the previous experiments in this dissertation found slow establishment of native species from seed, therefore an experiment was established to determine potential to apply smoke water derived from burnt vegetation or potassium nitrate to seeds of various native boreal plants to improve germination. The experiment assessing potential of common disturbance cues (nitrate and smoke) to act singly or in combination to increase seed germination over a wide range of boreal species is detailed in Chapter 7.

Chapter 8 concludes this dissertation and includes a research summary of the chapters, management recommendations and limitations of the current research program and some suggested directions and requirements for future research.

Documented responses of early plant establishment from in situ propagules and of soil quality properties using various soil handling techniques provide new knowledge on how LFH can be used for oil sands reclamation.

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CHAPTER II
POTENTIAL OF LFH DEVELOPED ON COARSE TEXTURED SOIL FOR RECLAMATION USE IN THE ATHABASCA OIL SANDS REGION, ALBERTA

2.1 INTRODUCTION

Use of topsoil for transfer as a propagule source for mine site revegetation is well documented in subtropical, temperate and arid regions; its applicability in boreal forest has not been widely researched (Tacey and Glossop 1980, Iverson and Wali 1981, Grant et al. 1996, Holmes 2001, Zhang et al. 2001). MacKenzie and Naeth (2010) found LFH (LFH mixed with upper mineral soil horizons) developed from a *Populus tremuloides* Michx. (trembling aspen)-*Picea glauca* (Moench) Voss (white spruce) mixed forest on a clay loam soil in the Athabasca Oil Sands Region provided sufficient seeds and vegetative propagules for establishment of many boreal forest understory species. Upland surface soil for salvage in this region is limited and many surface soils are coarse textured (sand), nutrient poor and rapidly drained (Turchenek and Lindsay, 1992). *Pinus banksiana* Lamb. (jack pine) dominates dry sandy soils and *Populus tremuloides* dominates less dry sites. Fewer seeds were found in *Pinus banksiana* soils than in forests on fine textured soils (loam to clay); however, old growth forests on fine textured soil have smaller seed banks (Archibold 1979, Fyles 1989, Qi and Scarratt 1998, Whittle et al. 1998, MacKenzie and Naeth 2010). Whether these surface soils can provide a propagule source for revegetation on post-mined oil sands landscapes is unknown.

Most propagules in upland boreal forests are contained in the organic layers (LFH layer) and upper few cm of mineral soil (Strong and La Roi 1983, Whittle et al. 1997, Qi and Scarratt 1998). Propagule abundance decreases with increasing soil depth in natural settings (Moore and Wein 1977, Granström 1986, Kramer and Johnson 1987, Hills and Morris 1992), thus deep salvage dilutes this propagule source. Little information is available for the oil sands region on soil propagule bank abundance, composition and distribution on coarse textured soil.

Salvaged surface materials placement results in variable propagule distribution. If salvaged materials are mixed, propagules can be redistributed evenly throughout the placed material or concentrated near the top or bottom. Deeply buried seeds and vegetative propagules are unlikely to emerge due to reduced carbohydrate reserves, light penetration and soil gas diffusion (Batson 1998, Benvenuti 2003).

This research was conducted to assess the soil propagule bank from LFH developed on a coarse textured soil and to determine its effectiveness in providing an alternative surface soil and in situ propagules for revegetation compared to the commonly used peat-mineral mix. Effect of salvage depth and placement depth on propagule abundance and distribution were evaluated.

2.2 MATERIALS AND METHODS

2.2.1 Research Site Description

The research area was 61 km north of Fort McMurray, Alberta, Canada, at the Syncrude Canada Ltd. Aurora North mine site (latitude 57^{o} 21' N, longitude 111^{o} 31' W) within the central mixed wood subregion of the boreal natural region (Natural Regions Committee 2006). The climate is cool temperate with short, cool summers and long, cold winters (Strong and Leggat 1992). Mean annual temperature is 0.3 ºC. The 1944 to 2007 long term average annual precipitation was 471.2 mm, with approximately 322.7 mm of rain and 148.5 cm of snow (Syncrude Canada 2008).

Soils in the region are typic mesisols (organic) in lowland areas and eluviated and orthic eutric brunisols (mineral) in uplands (Turchenek and Lindsey 1982). Pre-mined vegetation was representative of the mixed wood boreal forest for each soil. Undisturbed organic soils are dominated by *Picea mariana* (P.) Mill. (black spruce) and *Larix laricina* (Du Roi) K. Koch (tamarack); mineral soils are dominated by a coniferous-deciduous forest mix. Uplands typically consist of *Pinus banksiana*, *Populus tremuloides* and *Picea glauca* (Moench) Voss (white spruce) vegetation (Fung and Macyk 2000).

2.2.2 Donor Site Description, Salvaging, Sampling

The donor site was a 25 ha, 50 year old forest, harvested of timber during summer 2006, 4 to 6 months before salvage. Topography was gently to strongly undulating. Vegetation was dominated by *Pinus banksiana* and *Populus tremuloides* with a diverse understory of shrubs and herbaceous species. One area had an overstory comprised of *Pinus banksiana* and another area had a mix of *Pinus banksiana* and *Populus tremuloides*. Dominant soils were eluviated eutric brunisols; orthic eutric brunisols were present in *Pinus banksiana* stands. Average depth of the LFH layer was 5 cm, ranging from 2 cm in *Pinus banksiana* stands to 8 cm in mixed *Pinus banksiana* and *Populus tremuloides* stands.

Prior to salvage, the donor site was split into a 50 x 50 m grid and samples taken in each grid centre. To estimate abundance and depth distribution of seeds and propagules, at each quadrat center, a 7.5 cm diameter, 20 cm long, polyvinyl chloride core was driven into the soil with a mallet until flush with the ground without compressing LFH. Upper and lower halves of LFH layers were separated. Mineral soil intervals were 0 to 2.5, 2.5 to 5, 5 to 10, 10 to 15 and 15 to 20 cm. All 700 samples were stored at 4 ºC until analyses. Soil was removed from the core, sample intervals cut with a serrated knife and placed in polyethylene bags.

To test effects of salvage depth, LFH was salvaged at 10 (shallow salvage) and 25 cm (deep salvage) from the surface. Soils were salvaged in September 2005 using a D7 Caterpillar crawler tractor. Salvaged material was stored in small windrows (2 to 3 m high by 4 to 6 m wide) until placement.

2.2.3 Receiver Site Description, Experimental Design, Sampling

Two experimental sites were established, 350 m apart, on a north facing lean oil sands (sands with bitumen content insufficient for economic extraction) overburden dump. At one experimental site, 1 m of sand was placed on top of the overburden; at the other experimental site, 1 m of mixed 50 % sand and 50 % fen peat was placed. Experiments were placed on lower slopes of the overburden dump; slope varied from 10 to 20 % on the sand substrate and from 5 to 10 % on

the peat-sand mix substrate experimental sites. At each site a complete randomized design consisted of 10 and 25 cm salvage depths of LFH and 10 (shallow placement) and 20 cm (deep placement) placement depths of LFH (Figure 2.1). A control consisting of no LFH material was located on the peat-sand substrate. Each treatment was replicated three times; each replicate was 15 by 70 m to accommodate operational scale equipment and material availability.

In March 2006, donor materials were removed from windrows using a Hitachi 450LC excavator which placed materials into Caterpillar 777D haul trucks for transport. Haul trucks were loaded with approximately 55 m^3 of donor material; 20 cm placement treatments received four truck loads and 10 cm placement treatments received two truck loads. Distribution of forest types at the donor site varied, to reduce experimental error LFH from the *Pinus banksiana* stand were placed over peat-sand substrate and LFH from the *Pinus banksiana* - *Populus tremuloides* mixed stand were placed on sand substrate. Materials were placed as evenly as possible then spread with D8R and D6LPG Caterpillar crawler tractors.

To determine depth distribution of seeds and propagules, samples were taken in May 2006 every 10 m along two 60 m randomly located transects in each treatment using a 7.5 cm diameter polyvinyl chloride core. Samples were taken at 0 to 2.5, 2.5 to 5, 5 to 10 and 10 to 20 cm depth intervals from the surface. Maximum depth sampled was dependent on treatment. Controls were sampled to 5 cm; 10 cm placement treatments were sampled to 10 cm; 20 cm placement treatments were sampled to 20 cm. Samples were stored at 4 ºC until analyzed.

2.2.4 Growth Chamber Methods

Propagule emergence from donor and receiver sites were quantified in a growth chamber under controlled light and temperature by enumeration (Baskin and Baskin 1998). Donor site samples from two adjacent sample locations per sample depth interval were combined and thoroughly mixed by hand. Due to growth chamber space limitations, samples from each depth interval (5 to 10, 10 to 15, 15 to 20 cm) from two adjacent sample locations were composited and 220 cm^3

subsamples used for enumeration. Samples were spread to 2 cm depth in 10 x 12 cm plastic containers lined with 2 cm of Terra-Lite® metromix. Forty nine containers for each LFH layer and 50 containers of mineral soil for each depth interval were placed in the growth chamber for a total of 348 containers.

Similar procedures were carried out for the receiver site after the LFH was placed. Samples taken along each transect for each sample interval were composited and thoroughly mixed. From each composite sample 220 cm^3 was spread in 12.5 x 12.5 cm plastic trays. Twenty four containers with LFH for each depth interval per treatment and six containers with peat-mineral mix for each depth interval were placed in the growth chamber for a total of 180 containers.

The filled containers were placed randomly in the growth chamber. Soils were watered with distilled water as needed to prevent surface drying. Growth chamber temperatures represented growing conditions at the field site; 21 °C during the day for 16 h and 15 °C at night for 8 h. Emerged plants were identified and counted after two weeks and at monthly intervals thereafter for six months. Samples were remixed at two and four months to promote emergence by bringing up buried seeds and reducing thickness of the moss layer to promote light penetration (Thompson et al. 1997). A small number of plants were not identifiable because of death between enumeration periods or prior to identifiable structures emerging. Whether individual plants emerged from plant vegetative parts or from seeds or spores was determined by checking the root structure (presence of remnant vegetative parts) and presence of cotyledons (Lee 2004).

2.2.5 Statistical Analyses

Species were categorized into six plant groups based on morphology (woody, forb, grass, sedge, lily, pterydophyte). Unknown monocotyledons and dicotyledons were only included in the total estimate. Unidentified plants were excluded in calculations of species richness. Species nomenclature followed Moss (1993). Density data were presented as mean emergents m^{-2}. At the receiver site subsample data in each replicate were averaged to give one value per replicate.

Analyses were conducted in SPSS 18.0. One way fixed effects ANOVA was used to determine differences between sampling depth intervals at the donor site for total propagule abundance and emergents from seed and vegetative propagules. One way fixed effects ANOVA was used to determine significant differences between LFH treatments and the control on peat-sand substrate for total propagule density at 0 to 2.5 cm (Zar 1999). Two way fixed effects ANOVA was used to determine effects of salvage and placement depths on total propagule density, excluding the control on peat-sand substrate where each experimental site and each depth interval to a maximum depth of 10 cm was analysed separately (Zar 1999). Significant main effects using one way ANOVA were further analyzed using least squares difference (LSD) post hoc test for significant differences between control and LFH treatments (Carmer and Swanson 1973). Significant interaction effects in the two way ANOVA were analyzed by comparing different LFH treatments using one way ANOVA, if main effects were significant, differences among treatments were further analyzed using LSD. Residuals of response variables did not meet assumptions of normality based on the Shapiro-Wilk test, or assumption of homogeneity of variances based on Levene's test. All data were rank transformed. Significance effects were evaluated at $p \leq 0.05$.

2.3 RESULTS AND DISCUSSION

2.3.1 Donor Site

From donor site samples there were 1,189 emergents m^{-2} from combined depths; emergent were from 31 plant species. Total propagule density and species richness significantly decreased with increased depth ($p \leq 0.001$) in the following order lower LFH > upper LFH > 0 to 2.5 cm > 2.5 to 5 cm = 5 to 10 cm = 10 to 15 cm = 10 to 20 cm. Emergents from seed and vegetative propagules were significantly greatest in LFH and emergents from vegetative propagules were significantly greater ($p \leq 0.001$) at 0 to 2.5 cm depth than other depth intervals in mineral soil; there was no significant difference between mineral soil depth intervals. Seventy three percent of the total propagule abundance was in LFH

layers (Table 2.1). Mean seed densities and species richness were comparable to other boreal forest studies, with 111 plants emerging from the organic layer and top 5 cm of mineral soil in 49 samples (Table 2.2). Woody plants accounted for 50 % of total emergence, forbs 19 %, grasses 14 %, pteredophytes 9 %, sedges 4 %, lily and typha 4 %. Woody plants were the most abundant plant group at each depth, with the exception of forbs at 15 to 20 cm depth. From combined depths, 24 species emerged from rhizomes and 19 from seed (Table 2.2). The proportion of plants emerging from rhizomes (71 %), increased with depth (Figure 2.2). Many of the species found in the soil propagule bank are not available at a commercial scale from seed suppliers or nurseries.

Archibold (1979) reported seed densities of 372 seeds m^{-2}, from 19 species, in burned mixed wood forest on coarse textured soils in central Canada. Moore and Wein (1977) reported seed densities of 590 ± 90 seeds m^{-2} in a *Picea-Pinus* forest in the Acadian Forest Region, Canada. Johnson (1975) found no viable seeds in a *Pinus banksiana* forest soil in the Northwest Territories, Canada. From a *Pinus banksiana* forest 643 seeds, from 15 species, emerged from the organic layer and top 6 cm of mineral soil from 288 samples (Whittle et al. 1998). More productive boreal forests on fertile soils had soil seed bank densities of 1,273 seeds m^{-2} (Hills and Morris 1992) to 9,108 seeds m^{-2} (MacKenzie and Naeth 2010).

Few studies determined emergence potential from under ground vegetative parts (rhizomes, suckers). Our study was the only one with more plants emerging from rhizomes than seeds. Archibold (1979) found approximately 13 % of total emergents sprouted from root fragments and Whittle et al. (1998) found 35 %.

The high proportion of plants emerging from vegetative propagules in our study relative to others may be attributed to differences in stand characteristics and sampling. In our study, sampling of the donor site was less than one year after tree harvesting. Canopy removal and disturbance can increase resources available for understory species; thus root densities of shrubs and herbaceous plants could have increased, resulting in increased vegetative propagules (Hautala et al. 2001). In other studies the soil propagule bank was sampled in spring, when more seeds

could have germinated because they had an overwinter period to break dormancy. Many seeds could have germinated in spring and summer resulting is fewer viable seeds in our estimates. The results from our study show how important roots or the bud bank is in contributing to plant establishment when used as a propagule source for reclaiming post-disturbed landscapes.

Similar results, for seed and vegetative propagule distribution with soil depth were found for other forest propagule banks. Seed densities, root abundance and species richness decreased with increasing depth and most propagules were contained in organic layers. Kramer and Johnson (1987) found most viable seed (67 %) occurred in the upper 5 cm of soil, with the remainder in the 5 to 10 cm mineral layer. Moore and Wein (1977) found higher seedling emergence from the 0 to 2 cm layer of organic soil in five study sites. Qi and Scarratt (1998) reported reduced seed density and species with depth; they found 20 species in organic samples and 70 seedlings of 7 species in mineral samples. Whittle et al. (1998) found increased emergence from seed in mineral soil than organic layers (117 emergents); emergents from root fragments were greater in the organic layer.

Number of species emerging from seed or root fragments declined with depth. Strong and La Roi (1983) found most roots of boreal trees (50 %) were confined to the upper 15 cm of soil, with soil texture determining maximum rooting depth. Maximum rooting depth for boreal trees was greatest on sandy substrates and lowest on organic deposits. Jackson et al. (1996) wrote a detailed literature review on root distributions for all terrestrial biomes and concluded root density decreased with soil depth; within the boreal forest root density declined from 2.1 to 3.8 kg m^{-3} in the upper 20 cm of surface soil to 0.1 kg m^{-3} below 25 cm.

Understanding propagule distribution provides insight into how deep surface soils can be salvaged. Salvaging too deep will result in diluting surface rich seed and vegetative propagule banks, potentially reducing number of propagules that can be used for reclamation. Deeper salvage in coarse textured soils may result in fewer differences in plant establishment compared to deeper salvage in fine

textured soils because roots are found at greater depths in coarse textured soil (Jackson et al. 1996, Schenk and Jackson 2002).

2.3.2 Receiver Site

From receiver site samples, 55 plants from 18 species emerged (Table 2.3). Fourteen species emerged from shallow salvaged treatments, 10 from deep salvaged treatments and 4 from the control. The majority of emergents originated from seed; lack of emergents from vegetative propagules could have been due to sampling method. Sampling loose soil with a core pushed horizontally oriented propagules downwards. Vegetative propagules greater than 7.5 cm in length were not cut by the corer and were excluded from the sample; thus number of viable propagules was underestimated. Obtaining individual samples from a larger area and larger volume would help collect more vegetative propagules. Average number of emergents varied, with no clear trends to differentiate treatments or depth differences (Table 2.4). There were few significant differences among LFH treatments. Significant interaction effects were detected at 5 to 10 cm, where both shallow salvage with shallow placement and deep salvage with deep placement had greater total propagule density. Further assessment of established vegetation in the field could provide a more accurate number of emergents.

The small propagule density in all treatments (losses > 90 %) compared to donor sites is consistent with other studies using donor soils on mine sites (Koch et al. 1996, Rokich et al. 2000, MacKenzie and Naeth 2007). MacKenzie and Naeth (2007) found over 90 % reduction in total density of LFH treatments salvaged from fine textured soils. Koch et al. (1996) found major losses in seed density from a Jarrah Forest soil throughout stripping (26 %), stockpiling (69 %) and spreading (87 %). During stripping, mineral soil underlying organic layers was removed at both our donor sites, which can significantly affect plant establishment through dilution. Stockpiling can reduce seed density survival with effects unrelated to stockpiling time (Rokich et al. 2000). However, effect of stockpiling in the cold temperate boreal forest has not been well researched.

The 10 cm salvage depth was expected to have higher concentrations of propagules than the 25 cm salvage depth. However, as described previously the sampling method used may not have accurately estimated densities. Growth chamber space was not readily available, therefore the volume of LFH used for emergence enumeration was limited. In future, where growth chamber space limits the volume of LFH used for enumeration, the volume could be reduced by screening roots and seeds from the soil reducing the total volume of material required for enumerating seedling emergence (Ter Heerdt et al. 1996).

Soil handling practices will affect root viability considering a high proportion of the propagule pool is vegetative propagules. Methods to estimate seed and vegetative propagule abundances and distributions on placed LFH in this study require improvement to capture plant emergents from vegetative propagules.

2.4 CONCLUSIONS

LFH developed on coarse textured upland surface soils under *Pinus banksiana* forests provides a rich source of seeds and vegetative propagules for revegetation and includes many species that are not commercially available for oil sands reclamation. Propagule abundance and species richness decreased with increasing soil depth, supporting salvage of LFH at shallow depths for native plant revegetation. Effects of salvage and placement depth on plant establishment require verification from established plants in the field.

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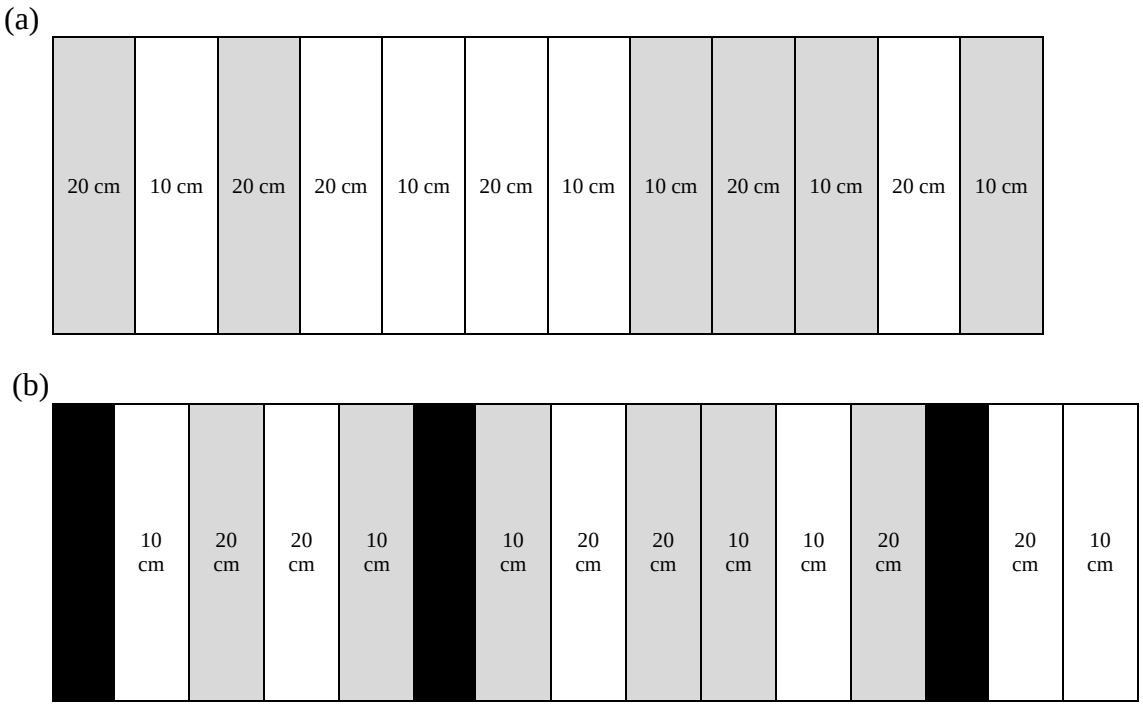

Figure 2.1 Experimental design of 10 and 20 cm of LFH placed on (a) sand and (b) peat-sand substrates. Gray areas represent 10 cm salvage depths; white areas represent 25 cm salvage depths; black areas represent controls with no LFH placement. Bottom of diagrams face north.

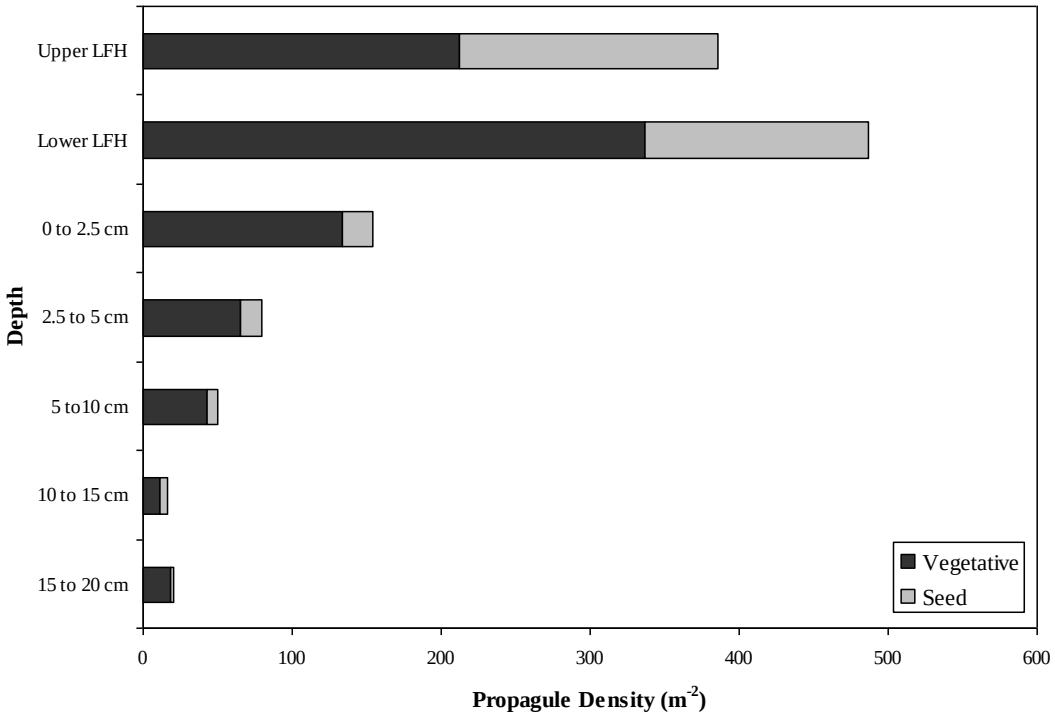

Figure 2.2. Mean soil propagule bank density m^{-2} for seeds and vegetative propagules that emerged in the growth chamber from samples at different depths from the donor site (LFH n=49, mineral n=50).

Table 2.1. Mean plant group abundance (emergents m^{-2}) and species richness of emergents in the growth chamber from soil sampled at various depths from the LFH donor site.

Depth	Total	Grass	Sedge	Forb	Woody	Lily/Typha	Pteridophyte	Species Richness
Upper LFH	385 (43.1)	74 (21.1)	7 (3.9)	77 (23.5)	189 (29.1)	2 (2.3)	36 (14.8)	19
Lower LFH	486 (51.3)	62 (15.1)	14 (6.3)	90 (29.8)	244 (32.5)	9 (5.5)	67 (16.1)	24
0 to 2.5 cm	154 (24.1)	7 (5.0)	25 (9.3)	25 (10.1)	61 (15.2)	36 (13.4)	0 (0.0)	16
2.5 to 5 cm	79 (16.2)	11 (5.8)	2 (2.3)	14 (6.2)	50 (11.3)	2 (2.3)	0 (0.0)	15
5 to 10 cm	49 (12.6)	7 (3.8)	2 (2.3)	2 (2.3)	34 (10.3)	2 (2.3)	2 (2.3)	11
10 to 15 cm	16 (6.5)	0 (0.0)	2 (2.3)	5 (3.2)	9 (4.4)	0 (0.0)	0 (0.0)	6
15 to 20 cm	20 (8.4)	0 (0.0)	0 (0.0)	11 (5.8)	9 (5.4)	0 (0.0)	0 (0.0)	6

Numbers in parentheses are standard errors. (LFH n=49, mineral n=50).

Table 2.2. Number of emergents in the growth chamber from soil propagule bank samples collected at the donor site.

Plant Species	LFH Layer				Mineral Soil (cm)									
	Upper		Lower		0 to 2.5		2.5 to 5		5 to 10		10 to 15		15 to 20	
	Seed	Veg	Seed	Veg	Seed	Veg	Seed	Veg	Seed	Veg	Seed	Veg	Seed	Veg
Grasses														
Agrostis scabra Willd.	1		1						1					
Elymus innovatus Beal.		2	1	1				2		1				
Oryzopsis pungens (Torr.) A.S. Hitchc.	9		19		3		3		1					
Sedges														
Carex siccata Dewey (Tall)		2	4	5	3	7				1	1			
Carex aenea Fern.			1		1			1						
Forbs														
Anemone multifida Poir.			1											
Aster ciliolatus Lindl.				1										
Circaea alpina L.	1													
Cornus canadensis L.	1			6		4		4				1		1
Epilobium angustifolium L.	2	1		3		2				1				1
Galium boreale L.						1								
Lathyrus venosus Muhl.	2		1			1	1							
Sonchus arvensis L.*	1													
Trientalis borealis Raf.				2										
Viola adunca J.E. Smith	2		29				1				1		1	2
Viola renifolia A.Gray	2		1											
Vicia americana Muhl.						1								
Unknown species	1													
Lilies														
Maianthemum canadense Desf.		1	1	24	1	14		1		1				

Seed = plants originating from seed; Veg = plants originating from vegetative propagules; * = non native species.

Table 2.2. Number of emergents in the growth chamber from soil propagule bank samples collected at the donor site (continued).

Plant Species	LFH Layer				Mineral Soil (cm)									
	Upper		Lower		0 to 2.5		2.5 to 5		5 to 10		10 to 15		15 to 20	
	Seed	Veg	Seed	Veg	Seed	Veg	Seed	Veg	Seed	Veg	Seed	Veg	Seed	Veg
Woody														
Alnus crispa (Ait.) Pursh.			1			4		1						
Arctostaphylos uva ursi (L.) Spreng.		29		6										
Cornus stolonifera Michx.						2	1	1						
Linnaea borealis L.		8		4										
Populus tremuloides Michx.	4	2	5	16		7		6		7		1		1
Potentilla tridentata Ait.						2		1						
Rosa acicularis Lindl.				1				1		1		2		1
Symphoricarpos albus (L.) Blake.								1						
Vaccinium vitis-idaea L. var. minus Lodd.		28	1	6		11		3		3				2
Vaccinium myrtilloides Michx.		4		1		3		7		4		1		
Unknown woody				2										
Club Moss														
Lycopodium complanatum L.		3		1										
Lycopodium obscurum L.		3		4										
Typha														
Typha latifolia L.			2		1									
Fern														
Unknown species	1		1						1					

Seed = plants originating from seed; Veg = plants originating from vegetative propagules; * = non native species.

Table 2.3. Number of emergents in the growth chamber from soil propagule bank samples taken in salvage, placement treatments on sand and peat-sand substrate.

Plant Species	Sand								Peat-Sand									
	10/10		10/20		25/10		25/20		10/10		10/20		25/10		25/20		Peat	
	Seed	Veg	Seed	Veg	Seed	Veg	Seed	Veg	Seed	Veg	Seed	Veg	Seed	Veg	Seed	Veg	Seed	Veg
Grasses																		
Oryzopsis pungens (Torr.) A.S. Hitchc.	2						4		1		1		2		1			
Unknown species																	1	
Sedges																		
Carex siccata Dewey (Tall)			1		1				1									
Carex aenea Fern.							1		1									
Carex spp.																	3	
Forbs																		
Achillea millefolium L.	2																	
Aster ciliolatus Lindl.	1																	
Campanula rotundifolia L.							1				2							
Cardamine pensylvanica Muhl.			1															
Epilobium angustifolium L.	1						1											
Epilobium ciliatum Raf.											1		2					
Geranium bicknellii Britt.															1			
Galium boreale L.											1							
Hieracium umbellatum L.	1																	
Sonchus arvensis L.*	1				1													
Urtica dioica L.									1								8	
Lily																		
Maianthemum canadense Desf.						3								1				
Woody																		
Betula papyrifera Marsh.								1									1	
Prunus pensylvanica L.f.				1														
Vaccinium myrtilloides Michx.						1	1											

Seed = plants originating from seed; Veg = plants originating from vegetative propagules; * = non native species.

Table 2.4. Mean total plant emergents m^{-2} in the growth chamber in samples taken from each treatment placed on sand and peat-sand substrate.

Treatment (Salvage Depth / Placement Depth)	Sampling Depth (cm)	Sand		Peat-Sand	
10 / 10	0 to 2.5	0	-	6	(6.3)
	2.5 to 5	13	(6.3)	0	-
	5 to 10	25 [a]	(6.3)	13	(6.3)
10 / 20	0 to 2.5	6	(6.3)	6	(6.3)
	2.5 to 5	6	(6.3)	0	-
	5 to 10	0 [b]	-	19	(10.9)
	10 to 20	0	-	6	(6.3)
25 / 10	0 to 2.5	6	(6.3)	13	(6.3)
	2.5 to 5	19	(10.9)	6	(6.3)
	5 to 10	0[b]	-	6	(6.3)
25 / 20	0 to 2.5	6	(6.3)	0	-
	2.5 to 5	19	(10.9)	6	(6.3)
	5 to 10	6[a]	(6.3)	0	-
	10 to 20	13	(12.6)	0	-

Numbers in parentheses are standard errors. (n=3). In columns different letters denote significant differences between LFH treatments analyzed with two way ANOVA. Significant differences at $p \leq 0.05$. 2, rank transformed for data analysis.

CHAPTER III
LFH SALVAGE AND PLACEMENT DEPTH EFFECTS ON RECLAMATION OF OIL SANDS MINES IN THE BOREAL FOREST, ALBERTA, CANADA

3.1 INTRODUCTION

The Athabasca Oil Sands Region contains the largest deposit of oil sands in Canada, with 4,800 km^2 of boreal forest accessible to surface mining (Alberta Environment 2012). Reclamation of landscapes disturbed by oil sands mining is complex and multi-faceted. Surface mining leaves a reconstructed landscape of overburden dumps and consolidated tailings deposits. Oil sands mining in northeastern Alberta has disturbed approximately 715 km^2 (71,500 ha) (Alberta Environment 2012). Some barriers to reclamation are the massive scale of disturbances, chemical and physical properties of waste materials being reclaimed, suitability of salvaged reclamation materials and lack of commercially available supplies of diverse native plant seeds and propagules for revegetation.

The pre-disturbed landscape consists of a complex network of bogs, fens, ponds, lakes, streams, rivers and upland forests. Most land is comprised of bogs and fens and the post-disturbed landscape is mainly to be reclaimed to upland forests. The historical and common reclamation practice is to cap wastes (tailings dykes, overburden, coke dumps) with suitable mineral soil, followed by approximately 20 cm of peat-mineral mix (Fung and Macyk 2000). Peat-mineral mix consists of peat excavated from bogs or fens with some underlying fine or coarse textured mineral soil. After placement of peat-mineral mix, only a small number of commercially available trees and shrubs are planted; the remaining common boreal forest understory plants are expected to establish through natural recovery. Using peat-mineral mix to achieve current reclamation standards of diverse, self-sustaining boreal forest ecosystems similar to those in the surrounding region (Alberta Environmental Protection 1998) makes natural recovery problematic. Placement of deeply salvaged organic soil onto upland landscapes results in a

newly created surface soil that does not contain a seed bank with sufficient quantities of appropriate plant species and surface soil often lacks available nutrients such as potassium and phosphorous (MacKenzie and Naeth 2010).

Use of topsoil as a propagule source for mine revegetation is well documented for subtropical, temperate and arid regions, but not boreal forest (Tacey and Glossop 1980, Iverson and Wali 1981, Grant et al. 1996, Holmes 2001, Zhang et al. 2001, MacKenzie and Naeth 2010). Earlier work on salvage and placement of LFH (LFH layer with upper mineral soil horizon(s)) developed on clay loam textured soil from upland mixed wood forest on a disturbed landscape provided seeds and plant propagules in sufficient quantities for establishment of many understory species (MacKenzie and Naeth 2010). After two growing seasons, LFH applied at 20 and 10 cm depths on saline sodic overburden, had 39 and 24 plants m^{-2}, respectively. Peat-mineral mix, applied at 20 and 10 cm, had 26 and 20 plants m^{-2}, respectively. Most species with peat-mineral mix were monocotyledons, those with LFH were forbs and woody species. With 20 and 10 cm application depths of LFH canopy cover was 36 and 20 %, respectively, compared to 5 and 6 % on peat-mineral mix applied at 20 and 10 cm, respectively. LFH provided more available nutrients, such as potassium and phosphorous than peat-mineral mix. Potential for LFH to act as a single source of propagules for establishment of boreal forest plant communities on reclaimed landscapes thus exists.

The area available for LFH salvage in the Athabasca Oil Sands Region is limited and much LFH is developed on coarse textured, nutrient poor and rapidly drained soil (Turchenek and Lindsay 1992). *Pinus banksiana* Lamb. (jack pine) forests dominate these dry soils, with *Populus tremuloides* Michx. (trembling aspen) dominant on less dry sites. Fewer seeds have been found in *Pinus banksiana* soils than in forests on fine textured soils; however, old growth forests on fine textured soil can have smaller seed banks (Archibold 1979, Fyles 1989, Qi and Scarratt 1998, Whittle et al. 1998, MacKenzie and Naeth 2010). Forests developed on coarse textured soil are less fertile than fine textured soils (Fisher and Binkley, 2000). How successful these soils will be in providing propagules for revegetation and sustaining plant growth on post-disturbed landscapes is unknown.

Species establishment from donor materials mainly depends on salvage depth. Most propagules in boreal forests are in soil organic layers (LFH) and upper few cm of mineral soil (Strong and La Roi 1983, Whittle et al. 1997, Qi and Scarratt 1998), decreasing with increasing depth (Moore and Wein 1977, Granström 1986, Kramer and Johnson 1987, Hills and Morris 1992; Jackson et al. 1996). Thus, deep salvage dilutes propagules near the surface. Soil nutrients and organic matter vary with depth, with organic layers containing more organic matter, available nutrients and cation exchange sites than mineral horizons (Huang and Schoenau 1996, Arocena and Sanborn 1999). With increasing depth, available nutrients and organic matter decrease and exchangeable cations increase.

Applying salvaged surface materials results in variable propagule distribution. Propagules could be distributed evenly throughout placed material or concentrated near the bottom. Seeds unable to emerge at great burial depths are thought to be limited by seed carbohydrate reserves, light penetration and soil gas diffusion (Batson 1998, Benvenuti 2003). Most studies assessing donor materials as a seed source concluded shallow (10 cm) and deep (>20 cm) placements result in similar species establishment (Holmes et al. 2000, Rokich et al. 2000, MacKenzie and Naeth 2010). MacKenzie and Naeth (2010) did not attribute their results to application depth but to increased fine particle material in the upper 10 cm admixed during placement using large equipment.

Several substrates are available in the Athabasca Oil Sands Region, including peat-mineral mix and fine (loam to fine texture) and coarse textured (sand) parent material (mineral). Two general substrates are mineral soil and a mix of mineral soil and peat. Applying donor materials at shallow depths may be acceptable if a substrate can provide soil water and nutrients for successful establishment.

This research was conducted to determine effectiveness of LFH salvaged from coarse textured soils in providing an alternative cover soil and in situ propagules for revegetation of mines oil sands disturbances than the commonly used peat-mineral mix. The effect of salvage depth, application depth and substrate type on plant establishment and soil properties at on operational scale were evaluated.

3.2 MATERIALS AND METHODS

3.2.1 Research Site Description

The research area was 61 km north of Fort McMurray, Alberta, Canada, at the Syncrude Canada Ltd. Aurora North mine (latitude 57^{o} 21' N, longitude 111^{o} 31' W) in the central mixed wood subregion of the boreal natural region (Natural Regions Committee 1996). Climate is cool temperate with short, cool summers and long, cold winters (Strong and Leggat 1992). Mean annual temperature is 0.3 ºC. The 1944 to 2007 long term average annual precipitation was 471.2 mm, approximately 322.7 mm as rain and 148.5 cm as snow (Syncrude Canada 2008).

Soils are typic mesisols (organic) in lowlands and eluviated and orthic eutric brunisols (mineral) in uplands (Turchenek and Lindsey 1982). Pre-disturbance vegetation was representative of mixed wood boreal forest. Undisturbed organic soils are dominated by *Picea mariana* (P.) Mill. (black spruce) and *Larix laricina* (Du Roi) K. Koch (tamarack) and mineral soils by coniferous-deciduous forest. Uplands typically consist of *Pinus banksiana*, *Populus tremuloides* and *Picea glauca* (Moench) Voss (white spruce) (Fung and Macyk 2000).

3.2.2 Donor Site Description, Salvaging, Sampling

The 25 ha donor site was 50 year old forest, harvested of timber in summer 2006, 4 to 6 months before salvage. Topography was gently to strongly undulating. Vegetation was dominated by *Pinus banksiana* and *Populus tremuloides* with a diverse understory of shrubs and herbaceous species. One area had an overstory of *Pinus banksiana*, the other a mix of *Pinus banksiana* and *Populus tremuloides*. Dominant soils were eluviated eutric brunisols; orthic eutric brunisols were present in *Pinus banksiana* stands. Average depth of LFH was 5 cm, from 2 cm in *Pinus banksiana* stands to 8 cm in mixed stands.

LFH was salvaged at 10 (shallow salvage) and 25 cm (deep salvage) in September 2005 using a D7 Caterpillar crawler tractor. Salvaged material was stored in small windrows (2 to 3 m high, 4 to 6 m wide) until placement.

3.2.3 Receiver Site Description, Experimental Design, Sampling

Two experimental sites were established, 350 m apart, on lower slopes of a north facing, lean oil sands (bitumen content insufficient for economic extraction) overburden dump. At one site, 1 m of sand was placed on overburden; at the other, 1 m of mixed 50 % sand and 50 % fen peat (peat-mineral mix) was placed on overburden. Slope was 10 to 20 % on sand substrate and 5 to 10 % on peat-sand substrate. At each site a complete randomized design consisted of 10 and 25 cm salvage depths of LFH and 10 (shallow) and 20 cm (deep) placement depths of LFH (Figure 2.1). A control of no LFH was located on peat-sand substrate. A control could not be established on sand substrate due to limited space and high erosion potential of exposed sand. Each treatment was replicated three times; each replicate was 15 by 70 m to accommodate operational scale equipment.

In March 2006, donor materials were removed from windrows using a Hitachi 450LC excavator which placed materials into Caterpillar 777D haul trucks for transport. Haul trucks were loaded with approximately 55 m^3 of donor material; 20 cm placements received four truck loads and 10 cm placements received two truck loads. Distribution of forest types at the donor site varied; thus to reduce experimental error LFH salvaged from *Pinus banksiana* stands was placed over peat-sand substrate and LFH from the *Pinus banksiana* - *Populus tremuloides* mixed stand was placed on sand substrate. Materials were placed as evenly as possible, then spread with D8R and D6LPG Caterpillar crawler tractors.

Vegetation was assessed in mid July 2006, 2007 and 2008. Ten randomly located 1 m^2 quadrats were placed in each of upper, mid and lower slope positions in each treatment replicate. Plant density and canopy cover by species were determined in each quadrat in 2006; canopy cover by species and woody stem density were determined in following years. Species nomenclature followed Moss (1993).

Soils were sampled in August 2006 and 2008. In each treatment replicate, five random subsamples were taken in each of three slope positions and composited into a polyethylene bag, for a total of three samples per replicate. LFH and controls were sampled with a shovel to corresponding placement depths.

Soils were analyzed according to Carter (1993) unless otherwise noted. Saturation %, pH, electrical conductivity, sodium adsorption ratio, soluble cations (calcium, potassium, magnesium, sodium) and soluble anions (chloride, sulfate) were determined from saturated paste extract. Total nitrogen was analyzed by digestion with pre-treatment of Devarda's alloy to convert nitrate to ammonium. Total carbon was determined by combustion. Extractable cations (calcium, potassium, magnesium, sodium) and cation exchange capacity were determined with ammonium acetate at pH 7.0. Available phosphorus and potassium were determined using modified Kelowna extraction. Available nitrate was extracted with 2 molar potassium chloride. Available micronutrients (copper, iron, zinc, manganese) were determined using diethylene triamine pentacetic acid. Extractable boron was determined by hot water extraction and available sulphate by monocalcium phosphate extraction (Combs et al. 1998). Particle size was determined by hydrometer.

3.2.4 Statistical Analyses

Species were categorized into 6 plant groups based on morphology (tree, shrub, forb, grass, sedge, lily) and one plant group with a sum of all plants (total). Unknown monocotyledons and dicotyledons were only included in the total. Subsample data, including slopes, within each experimental unit were averaged to give one value per experimental unit for each variable. Species richness was calculated by totalling number of species per experimental unit or replicate. Diversity was calculated for each experimental unit as the Shannon-Wiener index (H') and evenness using the formula E = H'/log10R (Magurran 1988). Unidentified plants (2 to 5 per experiment) were excluded from diversity measures. Density data were presented as plants m^{-2}.

Analyses were conducted using analysis of variance (ANOVA) in SPSS 18.0. One way fixed effects ANOVA was used to determine significant differences between LFH treatments and the control on the peat-sand substrate (Zar 1999). Two way fixed effects ANOVA was used to determine effects of salvage depth

and placement depth, excluding the control on the peat-sand substrate, on plant establishment and soil chemical properties; for this each experimental site was analysed separately (Zar 1999). Years were analyzed separately to meet ANOVA assumption requirements. Significant main effects using one way ANOVA were further analyzed using least squares difference (LSD) post hoc test for significant differences between control and LFH treatments (Carmer and Swanson 1973). Significant interaction effects in two way ANOVA were analyzed comparing LFH treatments using one way ANOVA, if main effects were significant, differences among treatments were further analyzed using LSD. Not all residuals of response variables met assumptions of normality based on the Shapiro-Wilk test, or the assumption of homogeneity of variances based on Levene's test. Data that did not meet assumptions using raw data sets were transformed using log 10 or rank transformations. Significance effects were evaluated at $p \leq 0.05$.

3.3 RESULTS AND DISCUSSION

3.3.1 LFH Versus Peat-Sand

3.3.1.1 Vegetation

Over 3 years, 65 plant species were found; 61 in LFH and 41 in peat-sand treatments. Species richness increased over time and was significantly greater in LFH each year than in peat-sand (Table 3.1). Diversity and evenness did not significantly differ between LFH and peat-sand initially; however, by year 3 they were greater in LFH (Table 3.2). In LFH on sand substrate, 53 plant species were found over three years (Table 3.3).

Canopy cover of most plant groups increased with time, being greater in LFH than peat-sand except grass (Table 3.4). Grass in peat-sand was significantly greater than in LFH 25 cm salvage. Lily plants were not found in controls.

Density of most herbaceous plants in 2007 was not significantly different with peat-sand and LFH; 20 cm LFH placement had greater lily (Table 3.5). Shrub density increased over time, significantly greater in LFH than peat-sand each year

(Table 3.6). Tree density was greater in LFH treatments each year; only 10 cm salvage with 20 cm placement was significantly greater than peat-sand in 2008.

Mostly upland species adapted to well drained, drier conditions, such as *Populus tremuloides*, *Pinus bansksiana*, *Prunus pensylvanica* L.f. (pin cherry), *Vaccinium myrtilloides*. *Rosa acicularis* Lindl. (prickly rose) and *Maianthemum canadense* Desf. (wild lily of the valley) were found in LFH. Species in peat-sand, such as *Calamagrostis canadensis* (Michx.) Beauv. and *Salix* (willow), were found in transitional zones in poorly drained, wetter conditions. Greater tree, shrub and lily densities in LFH were due to their high abundance at the donor site. Vegetation properties such as richness, density and cover are reflective of LFH and peat-sand origins and thus expected. Species in peat-sand are not typical of upland forests (Beckingham and Archibald, 1996). Many dry land species in LFH appeared in peat-sand by 2007 and 2008 from LFH treatments via seed dispersal and vegetative expansion. Species such as *Achillea millefolium* L. (common yarrow), *Amelanchier alnifolia* (Nutt.) (saskatoon berry), *Arctostaphylos uva-ursi* (L.) Spreng. (kinnikinnick), *Carex siccata* Dewey (hay sedge), *Carex aenea* Fern. (bronze sedge), *Fragaria virginiana* Duchesne (strawberry), *Pinus banksiana*, and *Vaccinium myrtilloides* found in peat-sand were usually close to LFH plot edges (seed and vegetative expansion). Some species in peat-sand plot centers in 2007 and 2008 established from seed blown from parent plants (*Achillea millefolium*) or eroded with LFH by wind and water onto peat-sand plots (*Pinus banksiana*).

MacKenzie and Naeth (2010) also found greater native and woody plant densities on LFH from fine textured soils than peat-mineral mix; and LFH at 10 and 20 cm on saline-sodic overburden had significantly higher species richness and diversity. The plant community on LFH treatments was more similar to that of the donor site than peat-mineral mix (MacKenzie and Naeth 2010).

3.3.1.2 Soil chemistry

Soil properties varied among treatments with higher values of most in peat-sand relative to LFH treatments (Tables 3.7 to 3.11). LFH had significantly lower pH (Table 3.7) and significantly more extractable potassium (Table 3.8) and available

phosphorous (Table 3.9) in 2008. Greater total carbon, total nitrogen, electrical conductivity, pH and cation exchange capacity in peat-mineral mix were reported in other studies (McMillan et al. 2007, MacKenzie and Naeth 2010, MacKenzie and Quideau 2011, Pinno et al. 2012) from mixing peat with over stripped, alkaline mineral soil (Fung and Macyk, 2000). Peat-mineral mix often has less available and exchangeable potassium and phosphorous than LFH (MacKenzie and Naeth 2010, MacKenzie and Quideau 2011, Pinno et al. 2012). Available phosphorus is limiting in boreal forest soils (Van Cleve et al. 1983) and potassium on coarse textured and organic soils (Fisher and Binkley 2000).

Electrical conductivity and pH in LFH were more suitable for plants than peat-sand. Both are rated good in LFH and fair in peat-sand as per soil quality criteria (Alberta Soils Advisory Committee 1987).

3.3.2 Salvage And Placement Depth

3.3.2.1 Vegetation

Salvage and placement depth had little effect on diversity (Table 3.1). In 2008 species richness was greater with deep salvage than shallow.

Density of most herbaceous plant groups in 2006 was not affected by salvage or placement depth (Tables 3.5 and 3.12). Grass density in LFH on sand (Table 3.12) and peat-sand (Table 3.5) was significantly greater with shallow than deep salvage. There was a significant interaction effect for lily (Table 3.5); shallow salvage and deep placement had significantly greater density than other treatments and shallow salvage, shallow placement had lowest densities. Shallow salvage and placement had lowest shrub stem densities on peat-sand (Table 3.6).

Canopy cover varied with plant group over time on both substrates (Tables 3.4 and 3.13), being greatest with shallow salvage and deep placement. Placement depth had more effect with LFH on sand than on peat-sand (Tables 3.4 and 3.13).

Results contradict the few studies of salvage depth effects on plant establishment. Fair (2011) found 23 native boreal species on LFH salvaged at 15 cm and 19

species when salvaged at 40 cm. Rokich et al. (2000) found salvaging 10 cm of surface soil from *Banksiana* woodland increased (22.0 vs 15.7) species from 30 cm salvage. Tacey and Glossop (1980) found salvaging 5 cm of surface soil from jarrah forest increased species richness (42 vs 35) compared to 40 cm salvage.

Seed density, root abundance and species richness decrease with depth in natural soils and our propagule bank study confirmed this; however, shallow and deep salvages were similar in species richness. We had a difference of 15 cm between salvage depths whereas other studies had differences of at least 20 cm (Fair 2011, Rokich et al. 2000, Tacey and Glossop 1980). The deep salvage might not have been deep enough to dilute the propagule bank that would reduce number of plants and species establishing from the in situ propagule bank contained in the LFH. Species, climate and soil in jarrah forest and banksiana woodland are different from boreal forest and disturbance thresholds differ. We found most species established from vegetative propagules, and the experiment was on a north aspect, which could explain the few differences in diversity. If soils were salvaged below 25 cm, a threshold would likely be obtained and shallow salvage would result in establishment of more species in greater abundance.

Most studies found deep placements 30 to 60 cm) did not increase species richness or diversity and shallow (10 to 15 cm) placements often resulted in increased values (Rendente et al. 1987, Rokich et al. 2000, Bowen et al. 2005, Schladweiler et al. 2005). Our results were most similar to those of Holmes et al. (2001) who found slight differences in species richness between different placement depths. While greater placements had slightly more species there were periods where shallow placements had more. Plant communities are only three years old and it is likely too early to determine if ecological differences in diversity will exist. There is evidence to support deep placements result in increased productivity, which over time will mean lower species richness and diversity because of less interspace preventing recruitment (Bowen et al. 2005).

Greater densities of plant groups with shallow salvage were expected; however, small or non-significant effects of salvage depth were found for most herbaceous

groups. Greater tree, shrub, grass and lily densities from shallow salvage are not surprising considering deep salvage would dilute propagules in LFH. Fair (2011) found salvaging LFH on fine textured soil at 15 cm increased plant group densities compared to 40 cm salvage. Rokich et al. (2000) found greater species recruitment on a bauxite mine when soil was salvaged at 10 cm (254 seedlings in 5 m^2) compared to 30 cm (81.33 seedlings in 5 m^2). Tacey and Glossop (1980) found stripping 5 cm of topsoil significantly increased seedling establishment relative to stripping 40 cm in jarrah forest. Effects of salvage depth are also applicable to non-vascular species. Rochefort et al. (2003) found significantly more moss in 0 to 10 cm of surface soil from peatland than deep layers.

The difference in plant density response to salvage depth in this experiment might be explained by increased variability with large plot sizes and equipment for soil handling. In other experiments (Tacey and Glossop 1980, Rokich et al. 2000) salvage area and plot size were much smaller and smaller equipment was used. Salvaging soil from large areas with large equipment reduces depth control. Placement of deep salvaged soil containing large roots with large equipment did not mix LFH layers and mineral soil well, placing seed and root bearing LFH near surface at the receiver site, similar to shallow salvage.

Lack of significant differences between salvage depths could also be attributed to factors reducing emergence with shallow salvage such as soil temperature, soil water or propagule to soil contact. Shallow salvaged LFH contained more roots and organic matter and less sand, which could lead to less available water and soil contact for seed germination and emergence from propagules. Further research is needed since only 25 cm salvage was studied and with soils salvaged too deep a threshold could be reached resulting in few plants because of dilution.

Deeper placement generally results in greater plant cover and/or productivity (Power et al. 1976, McGinnies and Nicholas 1980, Halvorson et al. 1986, Rendente et al. 1997, Schladweiler et al. 2005). Zhang et al. (2001) found 8 cm of farmland topsoil in China over lead-zinc tailings significantly increased plant cover compared to 4 cm. Holmes et al. (2001) found cover of unfertilized plots

was greater with 30 cm of topsoil than 10 and 0 cm on a South African mine. Differences between placement depth were greater over time. Bowen et al. (2005) found that in south central Wyoming over 24 years, deeper placement resulted in increased grass cover; however, forb cover was greatest with no topsoil. Grass cover was significantly greater with 40 cm of topsoil than 0 and 20 cm, but not different than 60 cm. They attributed forb cover increase with shallow placement to less competition from grasses. Fair (2011) found LFH salvaged and placed at 15 cm resulted in a significant cover increase for most functional plant groups compared to LFH salvaged and placed at 40 cm. She attributed the cover increase with shallow salvage and placement to less dilution of the propagule bank.

Few studies have assessed effects of LFH or topsoil salvage depth on plant cover. Increased cover with shallow salvage would be expected as shallow salvage contained more organic matter and plant available nutrients. If placement depth is too shallow, available nutrients might not be sufficient for plants to respond with increased cover. It is not surprising deep placement of LFH on a nutrient poor substrate, such as sand, would result in greater cover considering there is more available nutrients and organic matter than with shallow placement. MacKenzie and Naeth (2010) assessed effects of placement depth of two surface soils on a saline-sodic overburden dump and found significant interaction effects with cover soil type and placement depth. LFH from fine textured surface soil placed at 20 cm had greater cover of all vascular plants than 10 cm placement. However, cover was not different between 20 and 10 cm placements with peat-mineral soil.

3.3.2.2 Soil chemistry

Effects of LFH salvage and placement depth on chemical properties varied with substrate, with shallow salvages on sand generally having highest values of most properties (Tables 3.14 to 3.18). Fewer significant differences in macro and micro nutrients were detected between salvage depths on peat-sand than sand and organic carbon and available nutrients were lower in LFH on sand (Tables 3.7 to 3.11). Shallow placed LFH on peat-sand substrate had soil properties similar to those of peat-sand substrate. More nutrients with shallow placement can be

attributed to higher concentrations in substrates; however, reduced nutrient uptake from lower plant productivity could be a factor. MacKenzie and Naeth (2010) found admixing increased with shallow LFH or peat-mineral mix applications, causing a change in soil chemistry with LFH more similar to that of the substrate.

Shallow salvage and deep placement had greater available macro and micro nutrients than other LFH treatments on sand and to a lesser extent on peat-sand. Significant interaction effects were found for total nitrogen in 2006 on peat-sand and for cation exchange capacity in 2006 and 2008 on sand. Increased soil organic carbon and nutrients with shallow salvage and deep placement help explain the greater cover. Shallow salvage better maintains organic carbon and macro and micro nutrients than deep salvage which can dilute the nutrient rich LFH layer.

3.4 RECLAMATION APPLICATIONS

3.4.1 Cover Soil Selection

Species established from LFH is an intrinsic value difficult to quantify. The biological value could become more obvious once diverse plant communities persist through environmental stress periods and ungerminated seeds in LFH emerge. Species perform numerous ecological functions, with increased richness and diversity often leading to increased ecological stability and more resilient and higher functioning plant communities (Tilman 1996, Peterson et al. 1998). Tilman (1996) conducted a long-term study on biodiversity effects on ecosystem stability and concluded that in drought years plant communities with more species were more resistant. The greater densities of dryland plants and canopy cover using LFH is because dryland species are adapted to the drier reclaimed landscapes.

Greater cover in LFH can be attributed to factors other than species adapted to drier landscapes, such as more available phosphorous and lower electrical conductivity and pH relative to peat-sand. Cover reflects protection plants are contributing against soil erosion, giving a good estimate of ecological significance and reflecting ecosystem function (Floyd and Anderson 1987). Using LFH rather

than peat-mineral mixes could reduce the need for phosphorous and potassium fertilizer. Peat origin in this experiment was a fen, more nutrient rich than bogs (Verhoeven et al. 1990) and there may be fewer nutrient deficiencies in fen peat. Little information exists on peat types for reclaimed cover soils, however fen peat in mineral mixes could be better for reclaiming upland soils than bog peat.

LFH has suitable soil properties for reclaiming upland landscapes. Soil pH is an important factor regulating plant growth (Havlin et al. 1999) and if elevated could result in deficiencies of ions unavailable at high pH (Howat 2000). Electrical conductivity is an indicator of soil salinity, which can limit plant growth by water imbalance or ionic imbalances resulting in increased energy use (Havlin 1999). Growth inhibition in salt sensitive species is primarily by toxicity from sodium and chloride ions. Most boreal species are intolerant of saline soils (Purdy et al. 2005). LFH use almost ensures electrical conductivity will be rated as good by soil quality criteria (Alberta Soils Advisory Committee 1987), because there are few naturally saline areas in the mineable oil sands region (Purdy et al. 2005).

3.4.2 Substrate Considerations

Key determinants affecting plant establishment and growth are species requirements, substrate quality, annual precipitation and quality and depth of replaced soils (Hargis and Redente 1984, Merrill et al. 1998). Where underlying substrate has adverse characteristics for root growth, depth of soil replaced depends on nature and severity of the substrate, increasing with severity of adverse properties (Hargis and Redente 1984). This can explain placement depth having more effect on sand than peat-sand. Fewer cover differences for most plants with LFH on peat-sand could result from substrate providing high organic matter, allowing plants in shallow placement to access more water and nutrients.

Low cation exchange capacity of LFH on coarse textured soils on coarse textured substrates limits fertility of LFH treatments, as available nutrients not used by plants can be leached. Boron, copper and zinc deficiencies are most common on coarse textured soils and acidic peats (Ballard and Carter 1986), thus layering

LFH over peat-mineral mix with fen peat could help offset these constraints. Increased soil oxygenation after lowering the water table enhances nutrient mineralization (carbon bound nitrogen, sulphur, organically bound phosphorus), which can reduce fertility of peat (Holden et al. 2004). Leaching is complicated by environmental (temperature, redox potential, pH) and substrate factors (decomposition stage, organic matter quality, nutrients, soil solution chemistry, chemical and biological inhibitors to microbial activity) making it difficult to determine causes of shifts in available and exchangeable nutrients in peat-sand. Micro nutrient availability in soils with high organic matter, such as peat, is limited by the strong affinity of peat with many micro nutrient cations (Haynes and Swift 1985). Thus plants in peat-sand can become micro nutrient deficient.

Greater canopy cover on multiple treatments on peat-sand are attributed to mixing peat-sand with LFH during placement. The chemistry of peat-sand underlying LFH would influence LFH surface soil chemistry. Shallow placement of LFH on substrates with more organic matter, nutrients and water holding capacity could help reduce the need for deep applications of LFH. Where subsoil properties are not limiting, topsoil amount and quality becomes less important (Schuman and Power 1981). Long term effects on plant community establishment from placing LFH developed on sandy parent material with low organic carbon on a substrate that has more organic carbon is unknown. Increased water holding capacity on peat-mineral substrate could shift a *Pinus banksiana* stand to mixed *Pinus banksiana* and *Populus tremuloides*. Plants in shallow LFH on peat-sand would be more influenced by substrate properties than those on deep LFH. For example, electrical conductivity was significantly greater with shallow placement on peat-sand. Caution should be taken layering LFH over peat-mineral substrate, because negative shifts in plant community could occur if substrates are deficient or toxic.

3.4.3 Salvage and Placement Depth

LFH salvage depth impacts soil physical, chemical and biological properties which can affect how LFH should be placed for reclamation. Distribution of

organic matter and nutrients required for plant growth decreases lower in the natural soil profile (Jobbágy and Jackson 2001, Neville et al. 2002). However, in this research, available phosphorous increased with deep salvage. The donor site Bm horizon had more available phosphorus than Ae (data not shown), thus available phosphorous increased with deep salvage. Lanoue (2003) found high phosphorous in B horizons in jack pine forests on coarse textured soils. Salvaging LFH on coarse textured soil would provide an increase in phosphorous; however, soil organic matter and other nutrient concentrations would decrease.

Recommending one salvage depth for all soil types might not be ideal to optimize LFH. Different plant communities could require different amounts of soil nutrients and organic matter to maintain productivity. Expectations can differ for diversity. For example, deep (20 to 30 cm) salvage increases volume of material for reclamation; however, increased depth limits suitability as a propagule source for revegetation and could reduce organic matter. Placing shallow salvaged (10 to 15 cm) LFH on selectively salvaged subsoil with the intent of creating biomass might not use LFH efficiently. Subsoil provides additional nutrients and using both materials means less available material for reclamation. These examples demonstrate different approaches for managing and using salvaged LFH. Shallow salvage should be targeted when reclaimed site productivity, and to a lesser extent, species diversity are primary objectives. Deep salvage should be targeted when the primary objective is obtaining maximum reclamation material volume.

Placement depth should be based on reclamation objectives and optimal use of material if quantities are limited. Optimal placement depth of LFH to sustain a mature, productive forest could be different than depth for diverse wildlife habitat. Important considerations for reclaiming productive forests are available soil water and growing space for tree roots (Rodrigue and Burger 2004). Deep soil positively influences mine soil productivity through increased rooting depth and greater water holding capacity (Torbert et al. 1988, Andrews et al. 1998). LFH placement for a less productive forest plant might be shallower than that for commercial forest. For increased species diversity, placement should be varied from shallow to deep (DePuit 1984); however, if propagules are buried too deeply

they could lie dormant and lose viability, or germinate but never successfully establish. If soil is applied at shallow depths, propagules can emerge but available water and nutrients could limit successful plant establishment. Application of shallow soil layers over substrates with adverse properties (salinity, sodicity) requires further research. Initial growth might appear successful; but over time vigour could decrease as salts ingress into overlying soil.

Deep placement of LFH on nutrient poor substrate, such as sand, would result in greater cover considering there is more available nutrients and organic matter than with shallow placement. MacKenzie and Naeth (2010) found significant interaction effects with cover soil type and placement depth of two surface soils on a saline-sodic overburden dump. LFH on fine textured surface soil placed at 20 cm resulted in greater cover for all vascular plant groups than 10 cm placement. Cover was not different with 20 and 10 cm placement using peat-mineral soil. Increased cover with shallow salvage is expected as it contained more organic matter and plant available nutrients. If placement is too shallow available nutrients might not be sufficient for plants to respond with increased cover.

3.5 CONCLUSIONS

LFH on coarse textured upland surface soils developed under *Pinus banksiana* forests provides a rich source of seeds and plant propagules for revegetation; many of these species are not commercially available. LFH provides an alternative cover soil that can initially support an early successional plant community. Salvaging to 25 cm likely did not reach a dilution threshold to see significant reductions in plant density or diversity; however, shallow salvage had greater tree stem densities. Shallow salvage often resulted in higher canopy cover for most plant groups; however, responses were species specific.

Deep placement had little effect on plant density for most plant groups and generally resulted in greater canopy cover. A balance between maximizing the area over which propagules are redistributed, while providing sufficient resources for successful plant establishment is needed. If adequate diversity in plant

communities is a reclamation goal, LFH could be applied at shallower depths than those to maximize total diversity. When LFH was applied to peat-sand substrate, there were fewer differences between shallow and deep salvage in the resulting canopy cover and multiple treatments had greater cover compared.

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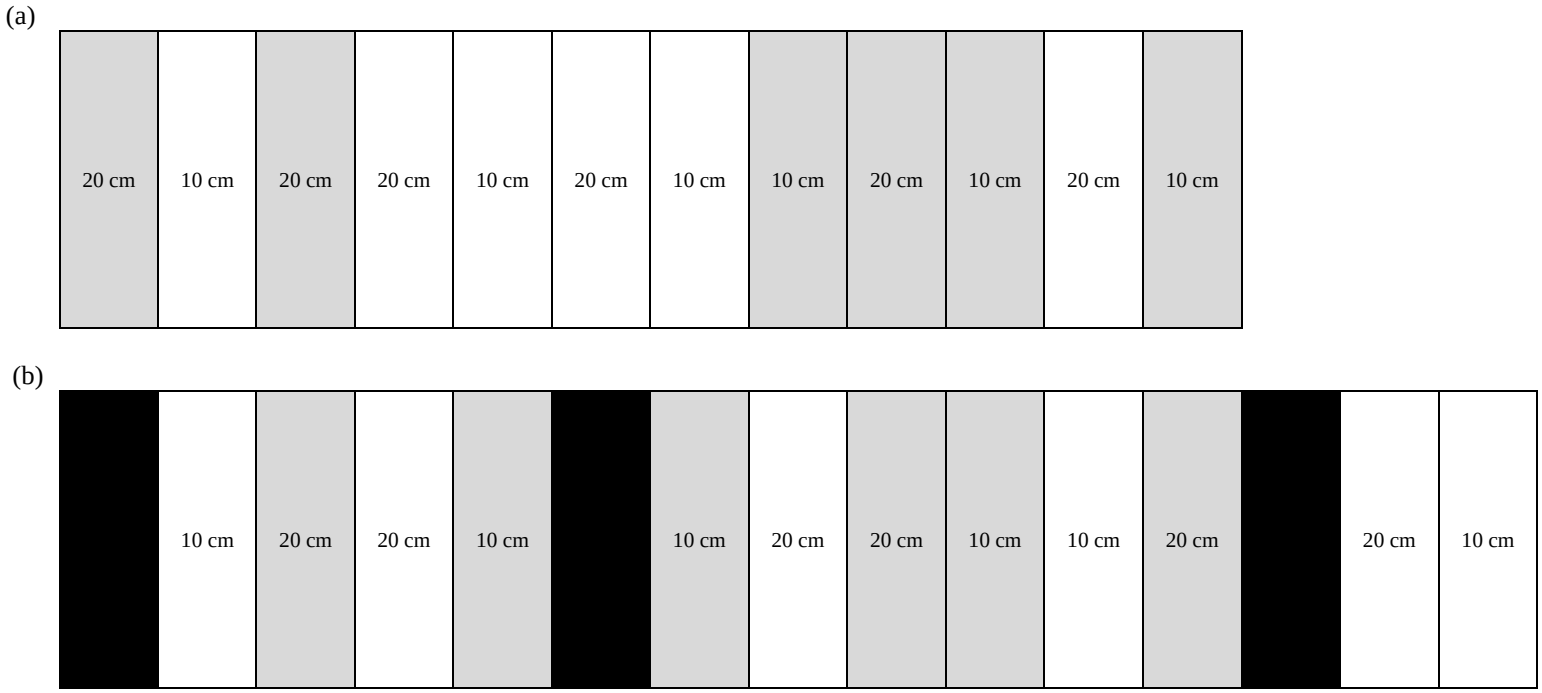

Figure 3.1. Experimental design of 10 and 20 cm of LFH placed on (a) sand and (b) peat-sand substrates. Gray areas represent 10 cm salvage depth treatments; white areas represent 25 cm salvage depth treatments; black areas represent controls with no LFH placement. Bottom of diagrams face north.

Table 3.1. Mean diversity measures for LFH treatments on sand substrate and LFH and control treatments on peat-sand substrate.

Year	Salvage Depth (cm)	Placement Depth (cm)	Sand						Peat-Sand					
			Richness		Diversity		Evenness		Richness		Diversity		Evenness	
2006	10	10	21.7	(1.20)	1.52	(0.45)	0.49	(0.14)	21.7*	(2.96)	1.70	(0.26)	0.60	(0.12)
		20	22.7	(0.33)	1.11	(0.23)	0.36	(0.08)	21.7*	(1.20)	2.14	(0.35)	0.70	(0.11)
	25	10	21.7	(0.33)	1.31	(0.20)	0.43	(0.06)	22.3*	(1.33)	2.07	(0.28)	0.70	(0.10)
		20	21.7	(1.45)	1.60	(0.04)	0.52	(0.03)	21.7*	(2.03)	1.90	(0.28)	0.60	(0.09)
	Control		-		-		-		9.3	(0.33)	1.43	(0.08)	0.60	(0.04)
2007	10	10	25.0	(0.00)	2.03	(0.20)	0.63	(0.06)	26.3*	(1.45)	1.80	(0.18)	0.55	(0.06)
		20	26.7	(0.33)	2.24	(0.12)	0.68	(0.04)	26.3*	(1.86)	1.95	(0.05)	0.60	(0.02)
	25	10	27.7	(1.76)	1.93	(0.08)	0.58	(0.01)	26.0*	(1.00)	1.99	(0.10)	0.61	(0.03)
		20	28.7	(2.03)	1.98	(0.32)	0.59	(0.08)	27.7*	(2.03)	2.13	(0.23)	0.65	(0.08)
	Control		-		-		-		17.3	(1.45)	1.64	(0.35)	0.59	(0.14)
2008	10	10	23.0	(1.00)	2.25	(0.12)	0.72	(0.03)	24.3*	(2.60)	1.86	(0.05)	0.59	(0.03)
		20	23.7	(0.33)	2.19	(0.09)	0.69	(0.03)	25.3*	(0.33)	2.06	(0.15)	0.64	(0.05)
	25	10	27.0	(2.52)	2.16	(0.05)	0.66	(0.03)	30.0*	(3.79)	2.20	(0.01)	0.65	(0.02)
		20	25.7	(2.40)	2.20	(0.17)	0.68	(0.03)	27.0*	(2.08)	2.07	(0.11)	0.63	(0.05)
	Control		-		-		-		17.7	(0.88)	1.63	(0.36)	0.56	(0.12)
P values														
One Way ANOVA														
	2006								0.002		0.333[2]		0.871[2]	
	2007								0.006		0.925[2]		0.917[2]	
	2008								0.035		0.152[2]		0.831[2]	
Two Way ANOVA														
2006	SD		0.621		0.633		0.579		0.872		0.833		0.891	
	PD		0.621		0.820		0.820		0.872		0.647		0.707	
	SD x PD		0.621		0.232		0.212		0.872		0.334		0.428	
2007	SD		0.123		0.412		0.245		0.767		0.258		0.345	
	PD		0.354		0.529		0.612		0.624		0.372		0.476	
	SD x PD		0.812		0.697		0.688		0.624		0.954		0.907	
2008	SD		0.138		0.744		0.285		0.185		0.102		0.449	
	PD		0.859		0.965		0.965		0.703		0.690		0.671	
	SD x PD		0.597		0.673		0.499		0.452		0.119		0.373	

Data are mean and (standard error), n=3. SD = salvage depth; PD = placement depth. In columns * denotes LFH treatments significantly different from the control at $p \leq 0.05$. [2] rank transformed for data analysis.

Table 3.2. Mean canopy cover of plant species on sites where LFH and controls were placed on peat-sand substrate.

Species	2006					2007					2008				
	10/10	10/20	25/10	25/20	Control	10/10	10/20	25/10	25/20	Control	10/10	10/20	25/10	25/20	Control
Achillea millefolium L.	0.00	0.00	0.00	T	0.00	0.00	T	0.01	0.20	0.00	0.02	0.02	0.04	0.02	0.05
Agrostis scabra Willd.	0.00	0.00	0.00	0.00	T	T	0.00	0.09	0.01	0.05	0.02	0.00	0.03	0.00	0.23
Agropyron trachycaulum (Link) Malte	T	0.00	0.00	0.00	0.11	0.00	0.00	T	0.00	0.10	0.00	0.00	0.02	0.00	0.00
Alnus crispa (Ait.) Pursh	0.01	0.02	0.00	0.02	0.00	0.03	0.12	T	0.41	0.00	0.01	0.04	0.00	0.18	0.00
Amelanchier alnifolia (Nutt.)	0.02	0.02	0.00	0.02	0.00	0.07	0.05	0.04	0.04	0.00	0.19	0.34	0.09	0.06	T
Anemone multifida Poir.	0.00	0.00	0.00	0.00	0.00	0.00	0.01	T	0.00	0.00	0.00	0.04	0.01	0.01	0.00
Apocynum androsaemifolium L.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.02	0.00
Aralia nudicaulis L.	0.01	T	T	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.02	0.02	0.03	0.04	0.00
Arctostaphylos uva-ursi (L.) Spreng.	0.02	0.02	0.01	0.04	0.00	0.05	0.10	0.08	0.08	0.00	0.29	0.49	0.38	0.86	T
Aster ciliolatus Lindl.	0.01	0.04	0.01	0.02	0.00	T	0.02	0.01	T	0.00	0.00	0.00	0.00	0.00	0.00
Aster conspicuus Lindl.	0.00	T	0.00	0.00	0.00	0.10	0.33	0.11	0.33	0.00	0.44	1.41	0.28	0.79	0.05
Calamagrostis canadensis (Michx) Beauv.	0.00	0.00	0.00	0.00	0.00	0.01	0.06	0.14	0.02	0.18	0.79	0.17	0.02	0.16	2.97
Campanula rotundifolia L.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00
Carex aurea Nutt.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02
Carex sp.	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.14	0.47	T	0.00	0.00	0.46
Carex siccata Dewey	0.06	0.02	0.04	0.01	0.00	0.83	1.88	0.28	0.26	0.02	7.66	8.52	0.94	1.48	0.10
Carex aenea Fern.	0.05	0.06	0.01	T	0.00	0.36	0.78	0.28	0.07	0.04	1.20	2.88	0.72	0.56	0.08
Chenopodium album L.	0.25	0.04	0.05	0.01	0.17	0.09	0.16	0.14	0.06	0.01	0.00	0.00	0.00	0.00	0.01
Atriplex subspicata (Nutt.) Rydb.	T	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Chenopodium capitatum (L.) Aschers.	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00	T	0.00	0.00	0.00	0.00	0.00	0.00
Comandra umbellata (L.) Nutt.	0.01	0.01	T	0.02	0.00	0.01	0.09	0.01	0.01	0.00	0.14	0.31	0.07	0.03	0.00
Corydalyis aurea Willd.	0.02	T	T	0.00	T	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cornus canadensis L.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	T	0.00
Corydalyis sempervirens (L.) Pers.	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Crepis tectorum L.	0.00	T	0.00	T	0.00	0.09	0.67	0.10	0.06	0.10	2.55	7.00	1.83	2.21	0.45
Deschampsia cespitosa (L.) Beauv.	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Dicot	T	T	T	0.01	T	T	0.00	0.00	T	0.00	0.00	0.00	0.00	0.00	T
Dracocephalum parviflorum Nutt.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	T	0.01	0.00	0.00	0.00	0.00	0.00
Elymus innovatus Beal	T	0.05	0.06	0.15	0.00	0.04	0.05	0.39	1.31	0.39	0.49	0.58	1.98	5.40	0.00
Epilobium angustifolium L.	1.69	0.67	0.58	0.61	0.20	6.04	7.82	4.98	4.35	4.98	10.84	10.83	8.24	11.82	1.04
Epilobium ciliatum Raf.	0.00	0.00	0.01	0.00	0.02	0.00	T	T	0.00	T	0.02	0.00	0.02	0.00	0.00

10/10 = 10 cm salvage depth, 10 cm placement depth; 10/20 = 10 cm salvage depth, 20 cm placement depth; 25/10 = 25 cm salvage depth, 10 cm placement depth; 25 cm salvage depth/20 cm placement depth. n=3. T = trace amounts of canopy cover <0.01%.

Table 3.2. Mean canopy cover of plant species on sites where LFH and controls were placed on peat-sand substrate (continued).

Species	2006					2007					2008				
	10/10	10/20	25/10	25/20	Control	10/10	10/20	25/10	25/20	Control	10/10	10/20	25/10	25/20	Control
Equisetum arvense L.	0.00	0.00	T	0.00	T	0.00	0.00	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.01
Erigeron philadelphicus L.	0.00	0.00	0.00	0.00	0.00	T	0.06	0.02	0.01	0.00	0.00	0.00	0.00	0.02	0.00
Fragaria virginiana Duchesne	0.01	T	0.00	0.01	0.00	0.08	1.00	0.06	0.27	0.00	0.02	0.08	0.18	2.48	T
Galium boreale L.	0.00	0.00	T	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.02	0.00	0.00
Galeopsis tetrahit L.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.01	0.00	0.00	0.20
Geranium bicknellii Britt.	0.18	0.10	0.05	0.05	0.00	0.96	7.10	0.90	0.45	0.00	0.05	0.01	0.03	0.02	0.00
Geum rivale L.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hieracium umbellatum L.	0.01	0.03	0.00	0.00	0.00	0.00	0.20	0.00	T	0.00	0.01	0.00	T	0.02	0.00
Lathyrus ochroleucus Hook.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.26	0.62	0.00
Lathyrus venosus Muhl.	0.00	0.00	0.18	0.06	0.00	T	0.00	0.58	0.31	0.00	0.00	0.00	0.83	0.64	0.00
Lepidium densiflorum Schrad.	0.00	0.00	0.00	0.00	0.00	T	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	T
Maianthemum canadense Desf.	T	0.03	0.00	T	0.00	T	0.01	T	T	0.00	0.01	0.04	0.05	0.04	0.00
Melilotus alba Desr.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00
Mertensia paniculata (Ait.) G. Don.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Oryzopsis pungens (Torr.) A.S. Hitchc	0.02	T	0.01	T	0.00	0.44	0.52	0.34	0.25	T	1.14	3.39	0.92	0.93	0.02
Pinus banksiana Lamb.	T	T	T	0.00	0.00	0.02	0.01	T	T	T	0.04	0.20	0.05	0.01	0.06
Potentilla norvegica L.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00
Populus tremuloides Michx.	0.04	0.07	0.02	0.05	0.00	0.04	0.19	0.02	0.00	0.05	0.27	0.57	0.09	0.04	0.02
Potentilla tridentata Ait.	0.00	T	0.00	T	0.00	0.00	0.04	0.00	0.05	0.00	0.00	0.10	0.02	0.14	0.00
Prunus pensylvanica L.f.	0.20	0.07	0.02	0.01	0.00	0.85	4.32	0.04	0.12	0.00	4.39	5.95	0.40	0.31	0.00
Rorippa islandica (Oeder) Bordes of Ed.	0.00	0.00	0.00	0.00	T	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.00
Rosa acicularis Lindl.	0.08	0.39	0.07	0.21	0.00	0.24	0.28	0.68	0.51	0.00	0.63	2.46	1.36	2.05	0.00
Rubus idaeus L. ssp. Melanolaslus Focke	0.00	0.00	T	0.02	0.00	0.00	0.12	0.01	0.01	0.00	0.09	1.39	0.08	0.02	0.00
Rubus pubescens Raf.	T	0.00	0.01	0.02	0.00	0.05	0.06	0.08	0.08	0.00	0.09	T	0.19	0.44	0.00
Salix sp.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.01	0.00	0.67
Solidago canadensis L.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.06	0.00
Solidago spathulata DC.	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.01	0.00	0.00	0.04	0.00	0.00	0.00
Sonchus arvensis L.	0.00	0.02	0.00	0.00	T	0.19	0.09	0.18	T	0.02	0.23	0.10	0.32	0.04	0.18
Stellaria longnifolia Muhl.	0.00	0.00	T	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00
Stellaria calycantha (Ledeb.) Bong.	T	0.00	0.01	T	0.01	0.00	0.00	0.00	0.00	T	0.00	0.00	0.00	0.00	0.00

10/10 = 10 cm salvage depth, 10 cm placement depth; 10/20 = 10 cm salvage depth, 20 cm placement depth; 25/10 = 25 cm salvage depth, 10 cm placement depth; 25 cm salvage depth/20 cm placement depth. n=3. T = trace amounts of canopy cover <0.01%.

Table 3.2. Mean canopy cover of plant species on sites where LFH and controls were placed on peat-sand substrate (continued).

Species	2006					2007					2008				
	10/10	10/20	25/10	25/20	Control	10/10	10/20	25/10	25/20	Control	10/10	10/20	25/10	25/20	Control
Thlaspi arvense L.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	T	0.00	0.00	0.02
Trientalis borealis Raf.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.01	0.00
Urtica dioica L.	0.04	0.03	0.04	0.01	0.07	0.26	0.12	0.18	0.03	0.27	0.07	0.09	0.13	0.01	0.59
Vaccinium myrtilloides Michx.	0.02	0.08	0.02	0.03	0.00	0.11	0.22	0.34	0.08	0.00	0.23	0.53	0.61	0.61	T
Vicia americana Muhl.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00
Viola adunca J.E. Smith	T	T	0.00	T	0.00	0.02	0.02	0.04	0.02	T	0.01	0.06	0.01	0.10	0.00

10/10 = 10 cm salvage depth, 10 cm placement depth; 10/20 = 10 cm salvage depth, 20 cm placement depth; 25/10 = 25 cm salvage depth, 10 cm placement depth; 25 cm salvage depth/20 cm placement depth. n=3. T = trace amounts of canopy cover <0.01%.

Table 3.3. Mean canopy cover of plant species on site were LFH was placed on sand substrate.

Species	2006				2007				2008			
	10/10	10/20	25/10	25/20	10/10	10/20	25/10	25/20	10/10	10/20	25/10	25/20
Achillea millefolium L.	0.00	0.00	0.00	0.00	0.00	0.11	0.02	0.02	0.00	0.00	0.37	0.40
Agrostis scabra Willd.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	T
Actaea rubra (Ait.) Willd.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00
Alnus crispa (Ait.) Pursh	0.06	0.04	0.02	0.02	0.00	T	0.08	0.06	0.06	0.00	0.05	0.05
Amelanchier alnifolia (Nutt.)	0.06	0.06	0.10	0.05	0.15	0.16	0.12	0.15	0.79	0.63	0.29	0.58
Anemone multifida Poir.	0.00	0.00	0.00	0.00	0.00	0.00	T	0.00	0.00	0.01	0.00	0.00
Apocynum androsaemifolium L.	0.00	0.00	0.02	0.01	0.00	0.03	0.01	0.03	0.01	0.01	0.18	0.07
Aralia nudicaulis L.	0.02	0.07	0.05	0.06	0.00	0.33	0.02	0.02	0.04	0.27	0.06	0.13
Arctostaphylos uva-ursi (L.) Spreng.	0.02	0.05	0.02	0.02	0.03	0.29	0.04	0.09	0.34	0.36	0.11	0.14
Aster ciliolatus Lindl.	0.01	0.03	0.02	0.05	0.01	0.00	0.01	0.00	0.00	0.00	0.03	0.00
Aster conspicuus Lindl.	0.00	0.00	0.00	0.00	0.12	0.29	0.24	0.56	0.49	0.33	0.23	0.37
Calamagrostis canadensis (Michx) Beauv.	0.45	0.03	0.01	T	0.53	0.66	0.23	0.27	1.55	0.53	0.75	0.35
Campanula rotundifolia L.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.00
Carex siccata Dewey	0.15	0.11	0.08	0.09	0.77	3.95	0.43	0.63	2.12	11.71	0.95	1.38
Carex aenea Fern.	T	0.01	T	0.00	0.15	0.60	0.04	0.09	0.47	0.54	0.15	0.08
Cerastium arvense L.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00
Chenopodium album L.	0.05	0.29	0.07	0.00	0.07	0.03	0.10	0.01	0.00	0.00	0.04	0.00
Comandra umbellata (L.) Nutt.	0.01	0.01	0.00	0.01	0.03	0.04	0.01	0.02	0.27	0.13	0.10	0.09
Cornus canadensis L.	0.00	T	0.00	T	0.00	0.00	0.01	T	0.00	0.10	0.01	0.04
Crepis tectorum L.	0.00	0.00	0.00	0.00	0.66	0.63	0.16	0.09	1.73	3.56	1.15	1.00
Dicot	0.05	0.00	0.00	0.00	0.01	0.00	0.00	T	0.00	0.00	0.00	0.00
Dracocephalum parviflorum Nutt.	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00
Elymus innovatus Beal	0.07	0.03	0.19	0.10	0.20	1.49	0.86	0.87	1.21	0.88	2.25	2.20
Epilobium angustifolium L.	3.93	7.05	2.81	2.49	3.95	8.89	4.91	7.84	3.47	6.76	6.26	7.41
Erigeron philadelphicus L.	0.00	0.00	0.00	0.00	0.04	0.04	0.00	0.01	0.00	0.00	0.00	0.00
Fragaria virginiana Duchesne	T	T	0.05	0.08	0.08	0.17	0.72	0.95	0.39	0.14	2.62	2.37
Galium boreale L.	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.00	0.00
Geranium bicknellii Britt.	0.03	0.11	0.03	0.07	0.80	3.21	0.33	0.42	T	0.00	T	0.00
Hieracium umbellatum L.	0.01	T	T	T	0.03	T	0.00	0.01	0.00	T	T	T
Lathyrus ochroleucus Hook.	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.38	0.00	0.00	0.20	0.27
Lathyrus venosus Muhl.	0.00	0.00	0.07	0.25	0.00	0.00	0.12	0.28	0.00	0.00	0.08	0.11
Maianthemum canadense Desf.	0.02	0.02	0.00	0.00	0.01	0.01	T	0.02	0.04	0.04	0.02	0.07

10/10 = 10 cm salvage depth, 10 cm placement depth; 10/20 = 10 cm salvage depth, 20 cm placement depth; 25/10 = 25 cm salvage depth, 10 cm placement depth; 25 cm salvage depth/20 cm placement depth. n=3. T = trace amounts of canopy cover <0.01%.

Table 3.3. Mean canopy cover of plant species on sites where LFH was placed on sand substrate (continued).

Species	2006				2007				2008			
	10/10	10/20	25/10	25/20	10/10	10/20	25/10	25/20	10/10	10/20	25/10	25/20
Oryzopsis pungens (Torr.) A.S. Hitchc	0.02	0.05	0.00	0.00	0.58	1.25	0.41	0.50	2.00	3.31	1.01	1.21
Pinus banksiana Lamb.	0.00	T	0.00	0.00	T	0.03	0.01	0.01	T	0.08	0.02	0.00
Potentilla norvegica L.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00
Populus tremuloides Michx.	0.14	0.40	0.09	0.14	0.11	0.92	0.06	0.27	1.03	2.58	0.32	0.36
Potentilla tridentata Ait.	0.00	0.01	0.01	0.01	0.01	0.02	0.04	0.20	0.07	0.06	0.04	0.15
Prunus pensylvanica L.f.	0.23	0.46	0.02	0.08	0.69	4.85	0.09	0.43	0.70	10.15	0.64	0.42
Lilium philadelphicum L.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	T	0.00	0.00	0.00	0.00
Ribes glandulosum Grauer	0.00	0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.00	0.00	0.00
Rosa acicularis Lindl.	0.14	0.12	0.26	0.53	0.18	2.15	0.78	1.02	0.31	2.84	0.82	2.91
Rubus idaeus L. ssp. Melanolaslus Focke	0.03	0.03	0.02	0.00	0.17	1.16	0.02	0.04	0.80	3.30	0.00	0.00
Rubus pubescens Raf.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.01
Solidago canadensis L.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	T	0.01	0.00	0.02
Solidago spathulata DC.	0.00	0.00	0.00	0.00	T	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sonchus arvensis L.	0.00	0.00	0.00	0.00	0.01	0.44	0.05	0.00	T	0.02	0.00	0.01
Symphoricarpos albus (L.) Blake	0.00	0.00	T	0.00	0.01	0.00	0.01	0.00	0.00	0.00	0.02	0.04
Taraxacum officiniale Weber	0.00	0.00	0.00	0.00	T	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Trientalis borealis Raf.	0.00	T	0.01	0.00	0.04	0.02	0.02	0.02	0.16	0.00	0.00	0.05
Vaccinium myrtilloides Michx.	0.08	0.09	0.07	0.12	0.12	0.19	0.33	0.11	0.57	0.53	0.44	1.18
Vaccinium vitis-idaea L. var. minus Lodd.	T	0.00	0.00	T	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Vicia americana Muhl.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	T	0.00	0.01	0.01
Viola adunca J.E. Smith	T	0.01	0.01	0.01	0.00	0.05	0.02	0.05	0.01	0.06	0.05	0.02
Maianthemum canadense Desf.	0.02	0.02	0.00	0.00	0.01	0.01	T	0.02	0.04	0.04	0.02	0.07

10/10 = 10 cm salvage depth, 10 cm placement depth; 10/20 = 10 cm salvage depth, 20 cm placement depth; 25/10 = 25 cm salvage depth, 10 cm placement depth; 25 cm salvage depth/20 cm placement depth. n=3. T = trace amounts of canopy cover <0.01%.

Table 3.4. Mean canopy cover for plant groups established on sites where LFH and controls were placed on peat-sand substrate.

Year	Salvage Depth (cm)	Placement Depth (cm)	Total		Trees		Shrubs		Forb		Grass		Sedge		Lily	
2006	10	10	2.74	(1.22)	0.04*	(0.02)	0.34*	(0.10)	2.23	(1.11)	0.02^{a}	(0.002)	0.10^{*a}	(0.01)	0.001^{*d}	(0.001)
		20	1.78	(0.86)	0.07*	(0.03)	0.60*	(0.25)	1.00	(0.61)	0.004^{*b}	(0.001)	0.08^{*a}	(0.02)	0.026^{*a}	(0.016)
	25	10	1.23	(0.73)	0.02*	(0.01)	0.13*	(0.06)	1.02	(0.64)	0.01^{*a}	(0.01)	0.05^{*b}	(0.03)	0.003^{*c}	(0.001)
		20	1.40	(0.51)	0.05*	(0.03)	0.35*	(0.14)	0.98	(0.39)	0.00^{*b}	(0.00)	0.02^{b}	(0.01)	0.004^{*b}	(0.001)
	Control		0.60	(0.15)	0.00	-	0.00	-	0.48	(0.12)	0.11	(0.04)	0.001	(0.002	0.00	-
2007	10	10	11.11^{*b}	(2.32)	0.05^{b}	(0.03)	1.35^{*b}	(0.27)	8.07*	(2.26)	0.45*	(0.07)	1.19^{*b}	(0.28)	0.001	(0.001)
		20	26.49^{*a}	(3.84)	0.20^{a}	(0.09)	5.21^{*a}	(0.88)	17.84*	(3.54)	0.58*	(0.08)	2.66^{*a}	(0.45)	0.011	(0.01)
	25	10	10.16^{*b}	(1.97)	0.02^{b}	(0.01)	1.20^{*b}	(0.15)	7.90*	(1.86)	0.48*	(0.04)	0.56^{*c}	(0.01)	0.003	(0.002)
		20	9.47^{*b}	(4.10)	0.06^{a}	(0.01)	1.25^{*b}	(0.70)	7.57*	(3.34)	0.27	(0.05)	0.33^{d}	(0.05)	0.001	(0.001)
	Control		1.52	(0.06)	0.06	(0.02)	0.03	(0.02)	0.94	(0.02)	0.29	(0.04)	0.20	(0.07)	0.00	-
2008	10	10	32.46^{*Ab}	(2.33)	0.31	(0.27)	5.83*	(2.26)	15.03*	(4.11)	1.96^{a}	(0.21)	9.33^{*a}	(2.45)	0.011	(0.00)
		20	47.70^{*Aa}	(7.18)	0.77	(0.50)	11.21*	(3.64)	20.72*	(3.09)	3.55^{a}	(0.94)	11.41^{*a}	(2.48)	0.044	(0.03)
	25	10	20.41^{*Bb}	(2.94)	0.14	(0.08)	2.94*	(1.08)	14.64*	(2.66)	1.00^{*b}	(0.17)	1.66^{*b}	(0.08)	0.046	(0.01)
		20	32.26^{*Ba}	(7.52)	0.05	(0.04)	4.10*	(0.57)	24.94*	(7.56)	1.09^{*b}	(0.25)	2.04^{*b}	(0.66)	0.035	(0.02)
	Control		7.24	(1.32)	0.02	(0.01)	0.68	(0.49)	2.68	(0.74)	3.22	(1.97)	0.64	(0.35)	0.00	-
p values																
One Way ANOVA																
Treatment	2006		0.444		0.045^{2}		<0.001^{1}		0.470		0.003^{2}		0.003^{2}		<0.001	
	2007		0.002		0.133^{2}		<0.001^{1}		0.012		0.011^{2}		<0.001^{2}		0.414	
	2008		0.002		0.170^{2}		0.008^{1}		0.038		0.040^{2}		<0.001^{2}		0.067	
Two Way ANOVA																
2006	SD		0.310		0.362^{2}		0.133^{1}		0.428		0.130^{2}		0.016^{2}		1.000	
	PD		0.663		0.185^{2}		0.181^{1}		0.413		0.049^{2}		0.165^{2}		0.000	
	SD x PD		0.532		0.755^{2}		0.479^{1}		0.444		0.130^{2}		0.408^{2}		0.006	
2007	SD		0.023		0.071^{2}		0.025^{1}		0.103		0.087^{2}		<0.001		0.814	
	PD		0.050		0.037^{2}		0.145^{1}		0.135		0.533^{2}		1.000		0.696	
	SD x PD		0.036		0.840^{2}		0.039^{1}		0.113		0.022^{2}		0.001		0.231	
2008	SD		0.038		0.222^{2}		0.058^{1}		0.698		0.001^{2}		0.001		0.239	
	PD		0.040		0.633^{2}		0.158^{1}		0.131		0.262^{2}		0.412		1.000	
	SD x PD		0.767		0.222^{2}		0.816^{1}		0.641		0.771^{2}		1.000		0.298	

Data are mean and (standard error), n=3. SD = salvage depth; PD = placement depth. In columns * denotes LFH treatments significantly different from the control. In columns different letters denote significant differences, where upper case letters denote a significant difference between salvage depth and lower case letters denote a significant difference between placement depth or for LFH treatments where interaction effects are significant. Significant difference at $p \leq 0.05$. [1] log10(X+0.0001) transformed for data analysis; [2] rank transformed for data analysis.

Table 3.5. Mean density (plants m^{-2}) for plant groups on sites where LFH and control were placed on peat-sand substrate in 2007.

Salvage Depth (cm)	Placement Depth (cm)	Total		Forb		Grass		Sedge		Lily	
10	10	7.5	(1.71)	3.0	(1.05)	0.5	(0.09)	1.3	(0.16)	0.1[c]	(0.03)
	20	8.8	(0.97)	2.2	(0.43)	0.3	(0.09)	1.1	(0.12)	0.9[*a]	(0.21)
25	10	8.4	(3.00)	3.8	(1.77)	0.4	(0.12)	1.1	(0.44)	0.3[b]	(0.08)
	20	9.6	(1.82)	4.6	(1.09)	0.3	(0.05)	0.6	(0.15)	0.4[*b]	(0.11)
	Control	4.7	(1.36)	3.0	(0.48)	0.7	(0.31)	0.9	(0.65)	0.0	-
p values											
One Way ANOVA		0.454		0.610		0.332		0.468[2]		0.001	
Treatment											
Two Way ANOVA											
Salvage depth		0.711		0.215		0.471		0.247		0.251	
Placement depth		0.555		0.989		0.095		0.218		0.004	
Salvage depth x Placement depth		0.981		0.544		0.807		0.628		0.022	

Data are mean and (standard error), n=3. In columns * denotes LFH treatments significantly different from the control. In columns different letters denotes significant differences for two way ANOVA. Significant differences at $p \leq 0.05$. [2] rank transformed for data analysis.

Table 3.6. Mean tree and shrub density (stems m^{-2}) on sites where LFH and controls were placed on sand and peat-sand substrates.

Year	Salvage Depth (cm)	Placement Depth (cm)	Sand				Peat-sand			
			Trees[1]		Shrubs		Trees		Shrubs	
2006	10	10	0.7	(0.19)	5.3	(0.92)	0.1	(0.07)	2.6*	(0.37)
		20	1.5	(0.74)	4.9	(0.74)	0.3	(0.08)	4.0*	(0.80)
	25	10	0.5	(0.09)	3.4	(0.68)	0.2	(0.11)	2.5*	(0.59)
		20	0.4	(0.12)	5.3	(0.49)	0.2	(0.02)	3.4*	(0.77)
	Control						0.0	-	0.0	-
2007	10	10	0.2[b]	(0.07)	5.0[b]	(0.49)	0.1[b]	(0.04)	3.1*	(0.02)
		20	1.1[a]	(0.39)	7.9[a]	(1.02)	0.2[a]	(0.06)	4.2*	(0.70)
	25	10	0.1[b]	(0.08)	5.0[b]	(0.85)	0.1[b]	(0.01)	3.4*	(0.44)
		20	0.4[a]	(0.09)	8.4[a]	(0.38)	0.1[a]	(0.00)	3.4*	(0.31)
	Control						0.1	(0.02)	0.0	-
2008	10 cm	10	0.5[a]	(0.19)	6.4[b]	(0.63)	0.1	(0.07)	3.3*	(0.44)
		20	1.2[a]	(0.40)	8.8[a]	(1.09)	0.4*	(0.10)	6.2*	(1.09)
	25	10	0.3[b]	(0.12)	4.9[b]	(0.75)	0.1	(0.06)	5.0*	(1.03)
		20	0.3[b]	(0.08)	8.0[a]	(0.65)	0.1	(0.04)	4.3*	(0.92)
	Control						0.02	(0.01)	0.7	(0.49)
p values										
One Way ANOVA										
Treatment	2006						0.115		0.007	
	2007						0.054		< 0.001	
	2008						0.021		0.004	
Two Way ANOVA										
2006	Salvage depth		0.063		0.329		0.889		0.636	
	Placement depth		0.469		0.322		0.282		0.113	
	Salvage depth x placement depth		0.256		0.154		0.412		0.719	
2007	Salvage depth		0.213		0.714		0.060		0.581	
	Placement depth		0.005		0.003		0.023		0.255	
	Salvage depth x placement depth		0.829		0.683		0.550		0.206	
2008	Salvage depth		0.030		0.183		0.073		0.905	
	Placement depth		0.081		0.009		0.119		0.273	
	Salvage depth x placement depth		0.504		0.676		0.073		0.076	

Data are mean and (standard error), n=3. In columns * denotes LFH treatments significantly different from the control. In columns different letters denotes significant differences for two way ANOVA. Significant differences at $p \leq 0.05$. [1] log10 transformed for data analysis.

Table 3.7. Mean values of chemical parameters from LFH and controls placed on peat-sand substrate.

Year	Salvage Depth (cm)	Placement Depth (cm)	pH		Electrical Conductivity		Sodium Adsorption Ratio		Total Carbon		Total Nitrogen		Cation Exchange Capacity	
					(dS/m)				(%)		(%)		meq 100 g^{-1}	
2006	10	10	6.22*	(0.18)	0.69^{*a}	(0.05)			1.13*	(0.18)	0.03^{*b}	(0.01)	3.56*	(0.38)
		20	5.99*	(0.13)	0.47^{*b}	(0.05)			1.09*	(0.06)	0.05^{*a}	(0.00)	3.34*	(0.03)
	25	10	6.34*	(0.11)	0.83^{*a}	(0.18)			0.86*	(0.22)	0.04^{*b}	(0.00)	3.68*	(0.40)
		20	6.04*	(0.03)	0.36^{*b}	(0.06)			0.74*	(0.06)	0.04^{*a}	(0.00)	3.51*	(0.37)
		Control	7.21	(0.09)	2.23	(0.17)			10.87	(1.41)	0.42	(0.04)	20.48	(1.15)
2008	10	10	6.47^{*a}	(0.15)	1.02^{*a}	(0.12)	0.16^{b}	(0.01)	1.22*	(0.23)	0.06*	(0.01)	3.46*	(0.42)
		20	6.00^{*b}	(0.14)	0.66^{*b}	(0.16)	0.24^{*a}	(0.02)	1.13*	(0.08)	0.04*	(0.00)	3.46*	(0.07)
	25	10	6.37^{*a}	(0.12)	1.44^{*a}	(0.26)	0.12^{b}	(0.03)	1.02*	(0.31)	0.04*	(0.01)	3.38*	(0.66)
		20	5.89^{*b}	(0.16)	0.54^{*b}	(0.06)	0.31^{*a}	(0.04)	0.79*	(0.18)	0.03*	(0.01)	3.13*	(0.07)
		Control	7.40	(0.03)	2.59	(0.11)	0.17	(0.03)	14.52	(1.69)	0.51	(0.09)	13.59	(1.46)
p values														
One Way ANOVA														
Treatment	2006		<0.001		<0.001				0.019^{2}		0.002		<0.001	
	2008		<0.001		<0.001				0.046^{2}		0.050		0.049^{2}	
Two Way ANOVA														
2006	SD		0.494		0.876				0.069		0.584		0.674	
	PD		0.064		0.009				0.614		0.126		0.583	
	SD x PD		0.795		0.250				0.828		0.031		0.948	
2008	SD		0.476		0.376		0.586		0.242		0.341		0.626	
	PD		0.010		0.005		0.001		0.476		0.202		0.765	
	SD x PD		0.970		0.147		0.127		0.746		0.627		0.765	

Data are mean and (standard error), n=3. SD, salvage depth; PD, placement depth. In columns * denotes LFH treatments significantly different from the control treatment analyzed with one way ANOVA. In columns different letters denote significant differences between LFH treatments analyzed with two way ANOVA. Significant difference at where $p \leq 0.05$. ^{2} rank transformed for data analysis.

Table 3.8. Mean extractable cation concentrations (meq 100 g^{-1}) from LFH and controls placed on peat-sand substrate.

Year	Salvage Depth (cm)	Placement Depth (cm)	Calcium		Magnesium		Potassium		Sodium	
2006	10	10	3.83^{*a}	(0.77)	0.28*	(0.14)	0.00	(0.00)	0.77	(0.32)
		20	2.48^{*b}	(0.20)	0.09*	(0.04)	0.00	(0.00)	0.93	(0.34)
	25	10	3.64^{*a}	(0.30)	0.10*	(0.10)	0.00	(0.00)	0.88	(0.07)
		20	2.29^{*b}	(0.30)	0.18*	(0.12)	0.00	(0.00)	1.08	(0.31)
		Control	31.07	(1.37)	1.84	(0.28)	0.00	(0.00)	0.11	(0.04)
2008	10	10	48.00*	(4.02)	0.36^{*a}	(0.04)	7.96^{*b}	(1.04)	0.19*	(0.05)
		20	58.33*	(6.43)	0.21^{*b}	(0.01)	14.16^{*a}	(2.35)	0.12*	(0.01)
	25	10	43.56*	(7.06)	0.22^{*b}	(0.02)	6.53^{b}	(0.61)	0.17*	(0.05)
		20	52.78*	(4.37)	0.20^{*b}	(0.01)	9.51^{*a}	(1.50)	0.13*	(0.02)
		Control	189.89	(18.75)	0.67	(0.02)	4.14	(0.10)	1.57	(0.13)
p values										
One Way ANOVA										
Treatment	2006		0.007[2]		0.008				0.141	
	2008		<0.001		<0.001		0.004		<0.001	
Two Way ANOVA										
2006	SD		0.687						0.663	
	PD		0.017						0.534	
	SD x PD		1.000						0.954	
2008	SD		0.400		0.017		0.081		0.884	
	PD		0.120		0.007		0.017		0.212	
	SD x PD		0.924		0.040		0.320		0.663	

Data are mean and (standard error), n=3. SD, salvage depth; PD, placement depth. In columns * denotes LFH treatments significantly different from the control. In columns different letters denote significant differences between LFH treatments analyzed with two way ANOVA. Significant differences at $p \leq 0.05$. [2], rank transformed for data analysis.

Table 3.9. Mean available nutrient concentrations (mg kg^{-1}) from LFH and controls placed on peat-sand substrate.

Year	Salvage Depth (cm)	Placement Depth (cm)	Nitrate		Phosphorous		Potassium		Sulphur	
2006	10	10	3.18[a]	(0.19)	23.44	(5.65)	19.00	(3.10)	17.22[*a]	(4.07)
		20	3.42[a]	(0.56)	24.67	(1.64)	12.22	(3.11)	10.78[*b]	(1.39)
	25	10	1.93[*b]	(0.39)	31.78	(3.14)	14.22	(5.08)	27.11[*a]	(11.39)
		20	1.98[*b]	(0.53)	30.89	(1.25)	18.89	(3.96)	5.44[*b]	(0.40)
		Control	3.59	(0.10)	0.22	(0.11)	25.22	(5.20)	426.00	(158.78)
2008	10	10	0.88[*]	(0.88)	19.44[b]	(3.16)	20.44	(1.31)	40.78[*a]	(4.92)
		20	0.34[*]	(0.18)	22.56[b]	(2.00)	26.56	(1.16)	26.33[*b]	(9.79)
	25	10	0.00[*]	(0.00)	31.89[a]	(0.62)	24.4	(3.18)	100.78[*a]	(21.25)
		20	0.23[*]	(0.23)	31.44[a]	(0.97)	32.33	(5.29)	20.56[*b]	(2.95)
		Control	2.07	(0.24)	0.00	(0.00)	21.56	(2.75)	595.67	(130.09)
p values										
One Way ANOVA										
Treatment	2006		0.032				0.289		0.001	
	2008		0.030				0.132		<0.001	
Two Way ANOVA										
2006	SD		0.016		0.064		0.815		0.529[2]	
	PD		0.752		0.962		0.793		0.011[2]	
	SD x PD		0.826		0.764		0.180		0.119[2]	
2008	SD				0.001		0.166		0.141[2]	
	PD				0.515		0.061		0.002[2]	
	SD x PD				0.391		0.789		0.054[2]	

Data are mean and (standard error), n=3. SD, salvage depth; PD, placement depth. In columns * denotes LFH treatments significantly different from the control. In columns different letters denote significant differences between LFH treatments analyzed with two way ANOVA. Significant differences at $p \leq 0.05$. [2], rank transformed for data analysis.

Table 3.10. Mean available micronutrient concentrations (mg kg^{-1}) from LFH and controls placed on peat-sand substrate.

Year	Salvage Depth	Placement Depth	Boron		Copper		Iron		Manganese		Zinc	
2006	10	10	0.17*	(0.03)	0.21*b	(0.01)	47.44*	(4.12)	8.63b	(0.35)	0.63*a	(0.05)
		20	0.13*	(0.02)	0.27*a	(0.00)	55.56*	(2.45)	10.09a	(2.07)	0.93*a	(0.15)
	25	10	0.21*	(0.04)	0.25*b	(0.02)	49.11*	(5.48)	5.79b	(1.66)	0.42*b	(0.09)
		20	0.21*	(0.01)	0.28*a	(0.01)	58.89*	(8.11)	6.72a	(0.75)	0.50*b	(0.02)
		Control	1.42	(0.07)	0.82	(0.09)	229.00	(29.56)	13.51	(2.51)	1.88	(0.14)
2008	10	10	0.61*a	(0.09)	0.02	(0.02)	0.00	(0.00)	5.22*	(1.42)	0.00	(0.00)
		20	0.79*a	(0.10)	0.02	(0.02)	0.00	(0.00)	3.32*	(1.02)	0.00	(0.00)
	25	10	0.46*b	(0.02)	0.09	(0.06)	0.03	(0.03)	4.74*	(1.72)	0.00	(0.00)
		20	0.49*b	(0.01)	0.02	(0.02)	0.28	(0.11)	2.62*	(0.43)	0.09	(0.09)
		Control	1.70	(0.23)	0.62	(0.01)	0.00	(0.00)	37.20	(0.69)	0.00	(0.00)
p values												
One Way ANOVA												
Treatment	2006		<0.001		0.001[2]		0.036[2]		0.057		<0.001[2]	
	2008		<0.001				0.502		<0.001			
Two Way ANOVA												
2006	SD		0.063		0.081		0.658		0.056		0.002[2]	
	PD		0.573		0.002		0.139		0.015		0.172[2]	
	SD x PD		0.573		0.177		0.882		0.855		0.307[2]	
2008	SD		0.025[2]						0.648			
	PD		0.130[2]						0.144			
	SD x PD		0.684[2]						0.931			

Data are mean and (standard error), n=3. SD, salvage depth; PD, placement depth. In columns * denotes LFH treatments significantly different from the control. In columns different letters denote significant differences between LFH treatments analyzed with two way ANOVA. Significant differences at $p \leq 0.05$. [2], rank transformed for data analysis.

Table 3.11. Mean soluble ion concentration (mg L^{-1}) of surface soil in 2007 from LFH and controls placed on peat-sand substrate.

Salvage Depth (cm)	Placement Depth (cm)	Calcium		Sodium		Magnesium		Potassium		Chloride		Sulphur	
10	10	206.22[*a]	(25.13)	9.11	(1.11)	23.22[*b]	(1.37)	10.00	(0.67)	7.89	(0.68)	398.00[*a]	(61.16)
	20	125.78[*b]	(47.16)	8.89	(0.29)	16.00[*bc]	(2.73)	10.56	(0.73)	9.44	(1.13)	256.00[*b]	(92.99)
25	10	319.00[*a]	(77.85)	8.44	(1.09)	32.89[*a]	(4.90)	9.11	(1.06)	6.56	(0.87)	779.78[*a]	(169.82)
	20	84.00[*b]	(11.59)	11.11	(2.66)	11.78[*c]	(1.61)	12.00	(3.56)	8.56	(1.09)	183.89[*b]	(30.01)
	Control	643.78	(12.24)	15.83	(0.95)	65.22	(10.07)	9.56	(1.85)	9.11	(2.47)	1675.56	(68.46)
p values													
One Way ANOVA													
Treatment		<0.001[2]		0.379[2]		<0.001[2]		0.923[2]		0.628		<0.001[2]	
Two Way ANOVA													
SD		0.814[2]		0.892[2]		0.390		0.783[2]		0.280		0.421[2]	
PD		0.005[2]		0.638[2]		0.001		0.539[2]		0.101		0.002[2]	
SD x PD		0.184[2]		0.839[2]		0.049		0.731[2]		0.823		0.053[2]	

Data are mean and (standard error), n=3. SD, salvage depth; PD, placement depth. In columns * denotes LFH treatments significantly different from the control. In columns different letters denote significant differences between LFH treatments analyzed with two way ANOVA. Significant differences at $p \leq 0.05$. [2], rank transformed for data analysis.

Table 3.12. Mean plant density (plants m^{-2}) for plant groups on sites where LFH was placed on sand substrate in 2007.

Salvage Depth (cm)	Placement Depth (cm)	Total		Forb		Grass[1]		Sedge		Lily	
10	10	12.1	(0.63)	3.5	(0.40)	1.1[a]	(0.21)	1.0	(0.10)	1.1	(0.21)
	20	11.7	(1.44)	3.2	(0.33)	0.8[a]	(0.09)	0.9	(0.21)	0.8	(0.08)
25	10	10.7	(1.32)	5.5	(1.45)	0.4[b]	(0.06)	0.7	(0.04)	0.4	(0.06)
	20	13.0	(2.53)	5.5	(1.87)	0.5[b]	(0.15)	0.9	(0.26)	0.5	(0.15)
p values											
Salvage depth		0.987		0.111		0.007		0.367		0.454	
Placement depth		0.584		0.919		0.485		0.712		0.907	
Salvage depth x Placement depth		0.442		0.877		0.445		0.466		0.601	

Data are mean and (standard error), n=3. In columns different letters denote significant differences at $p \leq 0.05$. [1] log10 transformed for data analysis.

Table 3.13. Mean canopy cover for plant groups on sites where LFH was placed on sand substrate.

Year	Salvage Depth (cm)	Placement Depth (cm)	Total		Trees[2]		Shrubs		Forb[2]		Grass[2]		Sedge[2]		Lily	
2006	10 cm	10 cm	5.59	(2.42)	0.14	(0.06)	0.62	(0.06)	4.19	(2.19)	0.47[a]	(0.25)	0.15	(0.01)	0.02[a]	(0.00)
		20 cm	9.08	(4.40)	0.40	(0.14)	0.85	(0.10)	7.61	(4.34)	0.08[a]	(0.03)	0.12	(0.01)	0.02[a]	(0.00)
	25 cm	10 cm	4.01	(1.24)	0.09	(0.04)	0.49	(0.22)	3.33	(1.05)	0.02[b]	(0.01)	0.08	(0.05)	0.00[b]	-
		20 cm	4.23	(2.42)	0.14	(0.04)	0.82	(0.15)	3.15	(0.82)	0.02[b]	(0.01)	0.09	(0.02)	0.01[b]	(0.00)
2007	10 cm	10 cm	9.58[b]	(0.88)	0.10[b]	(0.07)	1.35[b]	(0.18)	6.07[b]	(0.97)	1.11[a]	(0.04)	0.92[a]	(0.31)	0.01	(0.01)
		20 cm	32.08[a]	(3.54)	0.94[a]	(0.24)	8.85[a]	(2.98)	15.84[a]	(1.33)	1.90[a]	(0.36)	4.55[a]	(1.47)	0.01	(0.00)
	25 cm	10 cm	10.07[b]	(1.39)	0.06[b]	(0.04)	1.24[b]	(0.29)	7.66[b]	(0.93)	0.63[b]	(0.17)	0.47[b]	(0.22)	0.00	-
		20 cm	15.77[b]	(3.68)	0.27[a]	(0.07)	2.13[a]	(0.60)	11.84[a]	(2.59)	0.79[b]	(0.19)	0.72[b]	(0.32)	0.02	(0.01)
2008	10 cm	10 cm	18.64[b]	(2.47)	1.04	(0.77)	3.56[bc]	(0.45)	7.88	(0.30)	3.54[a]	(0.57)	2.59	(1.69)	0.04	(0.01)
		20 cm	49.00[a]	(4.16)	2.66	(0.20)	17.81[a]	(1.18)	12.41	(1.15)	3.84[a]	(0.22)	12.26	(4.40)	0.04	(0.03)
	25 cm	10 cm	19.34[b]	(3.41)	0.33	(0.13)	2.36[c]	(0.81)	13.76	(4.34)	1.77[b]	(0.67)	1.10	(0.23)	0.02	(0.01)
		20 cm	23.50[b]	(3.44)	0.36	(0.04)	5.31[b]	(1.17)	14.73	(1.67)	1.57[b]	(0.17)	1.46	(0.96)	0.07	(0.05)
p values																
2006	SD		0.255		0.055		0.615		0.500		0.002		0.231		0.001	
	PD		0.499		0.076		0.095		1.000		0.308		0.441		0.569	
	SD x PD		0.549		0.438		0.743		0.784		0.308		0.359		0.398	
2007	SD		0.020		0.053		0.165[2]		0.825		0.002		0.020		0.726	
	PD		0.001		0.002		0.016[2]		0.009		0.053		0.111		0.141	
	SD x PD		0.015		0.421		0.408[2]		0.149		0.421		0.217		0.107	
2008	SD		0.007		0.073		<0.001		0.133		0.003		0.063		0.888	
	PD		0.001		0.475		<0.001		0.100		0.478		0.273		0.576	
	SD x PD		0.005		0.172		<0.001		0.479		0.810		0.155		0.407	

Data are mean and (standard error), n=3. SD, salvage depth; PD, placement depth. In columns different letters denote significant differences at $p \leq 0.05$. [2], rank transformed for data analysis.

Table 3.14. Mean values of chemical parameters from LFH placed on sand substrate.

Year	Salvage Depth (cm)	Placement Depth (cm)	pH		Electrical Conductivity (dS/m)		Sodium Adsorption Ratio		Total Carbon (%)		Total Nitrogen (%)		Cation Exchange Capacity[2] (meq $100g^{-1}$)	
2006	10	10	5.48[a]	(0.07)	0.38[a]	(0.07)			1.14[a]	(0.03)	0.05[a]	(0.01)	3.66[a]	(0.07)
		20	5.12[b]	(0.05)	0.32[a]	(0.03)			1.32[a]	(0.10)	0.05[a]	(0.01)	4.32[a]	(0.18)
	25	10	5.49[a]	(0.06)	0.20[b]	(0.00)			0.86[b]	(0.07)	0.03[b]	(0.004)	3.84[a]	(0.46)
		20	5.30[b]	(0.05)	0.22[b]	(0.02)			0.78[b]	(0.07)	0.03[b]	(0.003)	3.10[b]	(0.21)
2008	10	10	5.94[a]	(0.11)	0.40[a]	(0.07)	0.27	(0.02)	1.14[a]	(0.14)	0.04[a]	(0.007)	3.24[b]	(0.16)
		20	5.44[b]	(0.18)	0.30[a]	(0.03)	0.38	(0.06)	1.41[a]	(0.15)	0.05[a]	(0.007)	4.09[a]	(0.41)
	25	10	5.82[a]	(0.14)	0.28[b]	(0.04)	0.33	(0.03)	0.74[b]	(0.07)	0.03[b]	(0.003)	3.11[b]	(0.14)
		20	5.64[b]	(0.11)	0.22[b]	(0.01)	0.34	(0.03)	0.68[b]	(0.04)	0.03[b]	(0.000)	2.72[c]	(0.06)
p values														
2006	SD		0.141		0.007				<0.001		0.012		0.045	
	PD		0.002		0.676				0.497		1.000		0.755	
	SD x PD		0.187		0.342				0.107		0.583		0.038	
2008	SD		0.785		0.047		0.683		0.001		0.015		<0.001	
	PD		0.039		0.106		0.158		0.386		0.368		0.859	
	SD x PD		0.275		0.617		0.239		0.165		0.479		0.005	

Data are mean and (standard error), n=3. SD, salvage depth; PD, placement depth. In columns different letters denote significant differences at $p \leq 0.05$. [2], rank transformed for data analysis.

Table 3.15. Mean available nutrient concentrations (mg kg^{-1}) from LFH placed on sand substrate.

Year	Salvage Depth (cm)	Placement Depth (cm)	Nitrate		Phosphorous		Potassium		Sulphur[2]	
2006	10	10	3.60	(1.22)	17.11	(2.82)	28.78	(1.90)	8.78^{Aa}	(3.44)
		20	5.04	(0.16)	19.22	(3.01)	35.00	(3.10)	4.44^{Ab}	(0.22)
	25	10	3.00	(1.30)	19.44	(2.31)	26.56	(2.91)	4.11^{Ba}	(0.11)
		20	3.11	(0.91)	24.78	(7.11)	27.22	(5.17)	3.67^{Bb}	(0.33)
2008	10	10	0.00	(0.00)	13.44	(2.78)	29.78	(2.21)	6.44^{a}	(1.78)
		20	0.12	(0.12)	16.56	(2.63)	33.89	(2.42)	3.89^{b}	(0.40)
	25	10	0.00	(0.00)	20.11	(2.26)	29.33	(3.47)	4.56^{a}	(0.48)
		20	0.00	(0.00)	22.44	(6.63)	26.67	(3.79)	2.78^{b}	(0.73)
p values										
2006	SD		0.243		0.382		0.188		0.003	
	PD		0.461		0.409		0.351		0.049	
	SD x PD		0.525		0.716		0.447		0.368	
2008	SD		0.402^{2*}		0.154		0.244		0.214	
	PD		0.572^{2}		0.514		0.819		0.011	
	SD x PD		0.670^{2}		0.925		0.298		0.744	

Data are mean and (standard error), n=3. SD, salvage depth; PD, placement depth. In columns different letters denote significant differences, where upper case letters denote a significant difference between salvage depth and lower case letters denote a significant difference between placement depth or for LFH treatments where interaction effects are significant at $p \leq 0.05$. [2] rank transformed for data analysis.

Table 3.16. Mean extractable nutrient concentrations (mg kg^{-1}) from LFH placed on sand substrate.

Year	Salvage Depth (cm)	Placement Depth (cm)	Calcium		Phosphorous		Potassium		Sulphur[2]	
2006	10	10	2.31[a]	(0.21)	0.34	(0.11)	0.00	(0.00)	0.21	(0.16)
		20	1.89[b]	(0.16)	0.18	(0.09)	0.00	(0.00)	0.44	(0.16)
	25	10	2.01[a]	(0.27)	0.34	(0.21)	0.02	(0.02)	0.41	(0.12)
		20	1.50[b]	(0.08)	0.04	(0.04)	0.06	(0.06)	0.37	(0.14)
2008	10	10	3.12[Aa]	(0.46)	0.04	(0.04)	0.02	(0.02)	0.00[c]	(0.00)
		20	2.51[Ab]	(0.11)	0.09	(0.09)	0.04	(0.04)	0.00[c]	(0.00)
	25	10	1.96[Ba]	(0.10)	0.00	(0.00)	0.00	(0.00)	0.22[b]	(0.04)
		20	1.67[Bb]	(0.10)	0.00	(0.00)	0.00	(0.00)	0.62[a]	(0.13)
p values										
2006	SD		0.114		0.619				0.690	
	PD		0.043		0.108				0.540	
	SD x PD		0.825		0.619				0.374	
2008	SD		<0.001[2]						<0.001[2]	
	PD		0.029[2]						0.006[2]	
	SD x PD		1.000[2]						0.006[2]	

Data are mean and (standard error), n=3. SD, salvage depth; PD, placement depth. In columns different letters denote significant differences, where upper case letters denote a significant difference between salvage depth and lower case letters denote a significant difference between placement depth or for LFH treatments where interaction effects are significant at $p \leq 0.05$. [2] rank transformed for data analysis.

Table 3.17. Mean available micronutrient concentration (mg kg^{-1}) from LFH placed on sand substrate.

Year	Salvage Depth (cm)	Placement Depth (cm)	Boron[2]		Copper		Iron		Manganese		Zinc	
2006	10	10	0.31^{A}	(0.01)	0.33	(0.04)	57.44^{Ab}	(2.63)	13.42^{A}	(1.11)	0.91^{A}	(0.11)
		20	0.36^{A}	(0.04)	0.30	(0.01)	70.11^{Aa}	(3.68)	18.29^{A}	(1.90)	1.14^{A}	(0.07)
	25	10	0.22^{B}	(0.01)	0.27	(0.02)	53.89^{Bb}	(2.86)	7.39^{B}	(0.51)	0.44^{B}	(0.05)
		20	0.21^{B}	(0.01)	0.28	(0.01)	55.22^{Ba}	(2.90)	8.88^{B}	(3.00)	0.50^{B}	(0.02)
2008	10	10	0.13	(0.02)	0.21	(0.03)	43.00^{c}	(3.03)	11.80^{A}	(1.65)	0.66^{Ab}	(0.04)
		20	0.13	(0.02)	0.22	(0.01)	62.11^{a}	(3.38)	21.46^{A}	(4.77)	0.90^{Aa}	(0.05)
	25	10	0.13	(0.00)	0.20	(0.02)	50.33^{b}	(2.27)	9.52^{B}	(1.16)	0.36^{Bb}	(0.02)
		20	0.10	(0.00)	0.25	(0.01)	54.22^{b}	(0.40)	8.33^{B}	(0.34)	0.51^{Bb}	(0.04)
p values												
2006	SD		<0.001		0.076^{2}		0.016		0.003		<0.001	
	PD		0.873		1.000^{2}		0.050		0.129		0.075	
	SD x PD		0.280		0.870^{2}		0.099		0.395		0.244	
2008	SD		0.285		0.458^{2}		0.916		0.005^{2}		0.000	
	PD		0.190		0.116^{2}		0.002		0.339^{2}		0.001	
	SD x PD		0.190		0.317^{2}		0.017		0.077^{2}		0.308	

Data are mean and (standard error), n=3. SD, salvage depth; PD, placement depth. In columns different letters denote significant differences, where upper case letters denote a significant difference between salvage depth and lower case letters denote a significant difference between placement depth or for LFH treatments where interaction effects are significant at $p \leq 0.05$. [2] rank transformed for data analysis.

Table 3.18. Mean soluble ion concentrations (mg L^{-1}) from LFH placed on sand substrate.

Salvage Depth (cm)	Placement Depth (cm)	Calcium		Sodium[2]		Magnesium		Potassium		Chloride[2]		Sulphur	
10 cm	10 cm	62.67^{A}	(13.39)	8.56	(0.44)	11.67^{A}	(1.64)	11.78^{A}	(1.56)	13.22^{a}	(1.75)	79.11^{Aa}	(16.78)
	20 cm	41.22^{A}	(5.94)	9.56	(1.39)	9.56^{A}	(0.40)	12.00^{A}	(1.39)	18.44^{a}	(4.31)	52.67^{Ab}	(4.50)
25 cm	10 cm	38.22^{B}	(7.12)	8.33	(0.67)	8.33^{B}	(0.69)	9.11^{B}	(0.48)	10.33^{b}	(1.39)	60.33^{Ba}	(6.26)
	20 cm	26.00^{B}	(3.03)	7.67	(0.19)	6.22^{B}	(0.48)	8.44^{B}	(1.06)	10.22^{b}	(0.59)	42.67^{Bb}	(5.68)
p values													
SD		0.044		0.129		0.008		0.031		0.010		0.003	
PD		0.077		0.806		0.056		0.857		0.471		0.049	
SD x PD		0.593		0.379		1.000		0.719		0.677		0.368	

Data are mean and (standard error), n=3. SD, salvage depth; PD, placement depth. In columns different letters denote significant differences, where upper case letters denote a significant difference between salvage depth and lower case letters denote a significant difference between placement depth or for LFH treatments where interaction effects are significant at $p \leq 0.05$. [2] rank transformed for data analysis.

CHAPTER IV
LFH SALVAGE AND PLACEMENT DEPTHS FOR BOREAL FOREST REVEGETATION IN NORTH EASTERN ALBERTA AS INFLUENCED BY ECOSITE AND SUBSTRATE

4.1 INTRODUCTION

Open pit mining of oil sands deposits in northeastern Alberta (Canada) has disturbed approximately 715 km^2 of the 4800 km^2 available for mining (Alberta Environment 2012). As of 2010, a reclamation certificate has been issued for only 1.04 km^2 of that disturbed land (The Royal Society of Canada 2010). Current regulations require disturbances be reclaimed to diverse, self-sustaining boreal forest communities similar to those in the surrounding region (Alberta Environmental Protection 1998). Most mined lands were formerly peatlands but are generally reclaimed to upland forests (Fung and Macyk 2000), which are quite different from pre-disturbed upland plant communities, especially the understory.

Oil sands' operators have recently been regulated to salvage LFH (LFH layer with upper mineral soil horizon(s)) as cover soil. LFH consists of the upper forest floor and underlying eluviated A horizon. In uplands it can provide a unique source of nutrients, organic matter, seeds, propagules, macro invertebrates, meso and micro fauna and woody debris (Brown 2010, MacKenzie and Naeth 2010). Its imited availability means operators must optimize its use across disturbed landscapes, as there is no other native seed source to supply diversity and abundance of species.

Research on LFH for boreal forest reclamation is limited to the mineable oil sands region (Lanoue and Qualizza 2001, Barbour et al. 2007, Brown 2010, MacKenzie and Naeth 2010). These studies found LFH enhanced native plant establishment and soil quality, and outperformed peat-mineral mix for native species establishment. Mines in other regions (alpine, subtropical and temperate forests, grasslands) topsoil transfer improved reclamation to diverse, self-sustaining, productive plant communities (Iverson and Wali 1981, Farmer et al. 1982, Koch et al. 1996, Smyth 1997, Holmes 2001, Zhang et al. 2001, Hall et al. 2010). When

reclaiming native ecosystems after mining, direct placement of soils containing viable propagules is one of the most economical ways to re-establish species diversity (Depuit 1984, Leck et al. 1989, Bell 2001).

Species emergence from LFH or topsoil is mostly dependent on salvage depth, which impacts propagule abundance and plant establishment. The general consensus is that shallow salvage (5 to 10 cm) results in greater recruitment of native plant species from in situ propagules than deep salvage (30 cm) (Tacey and Glossop 1980, Rockich et al. 2000). Most propagules in upland boreal forest soils are contained in the organic layer and upper few cm of mineral soil (Strong and La Roi 1983, Qi and Scarratt 1998, Whittle et al. 1998). Propagule abundance decreases with soil depth in natural settings (Moore and Wein 1977, Granström 1986, Kramer and Johnson 1987, Hills and Morris 1992); thus deep salvage dilutes propagule abundance. Soil particle size affects seed and root distribution, which is deeper in coarse textured (sand) than fine textured (loam to clay texture) soils (Chambers and Macmahon 1991, Schneck and Jackson 2002). Soil nutrients and organic matter vary with depth, with the organic layer of forest soils containing more organic matter, available nutrients and cation exchange sites than mineral horizons below (Huang and Schoenau 1996, Arocena and Sanborn 1999).

Very thin placement of LFH could be an effective way of distributing a small quantity over a larger area. However, this can be more suitable for seeds and might not supply sufficient soil nutrients or water to sustain plant growth. Soil texture might influence how well propagules emerge at various depths. Grant et al. (1996) found that most species did not emerge from depths greater than 5 cm and those that did were heavy seeds. Rokich et al. (2000) found no significant difference in seedling recruitment between 10 and 30 cm topsoil applications. Seeds unable to emerge from great depths are thought to be limited by seed carbohydrate reserves, light penetration and soil gas diffusion (Benvenuti 2003). Chen and Maun (1999) found *Cirsium pitcheri* (Torr. ex Eat.) Torr. & Gray (pitcher's thistle) seedling emergence occurred from a maximum depth of 6 cm in sand soils with most seedlings emerging from 2 cm. Bevenuti (2003) concluded emergence of *Datura stramonium* L. (jimsonweed) was negatively affected by

burial depth which was most detrimental in fine textured soils. If plant vegetative parts, such as rhizomes, are buried deep, insufficient energy reserves would prevent emergence (Batson 1998). Deep applications resulted in greater plant biomass and cover than shallow applications due to increased nutrients, organic matter and available water (Pinchak et al. 1985, Bowen et al. 2005). There is little information on burial depth and soil texture effects on boreal species emergence.

The objective of this study was to determine the potential for using LFH as a seed source for open pit mining on a plot scale. Effects of salvage and placement depth of LFH on plant establishment were assessed with different textured substrates from different boreal forest ecosites.

4.2 MATERIALS AND METHODS

4.2.1 Research Site Descriptions

Experiments were conducted at Syncrude Aurora North Mine (latitude 57° 21’ N, longitude 111° 31’ W) and Canadian Natural Resources Ltd. Horizon Mine (latitude 57° 21’ N, longitude 111° 48’ W) in the central mixed wood subregion of the boreal natural region (Natural Regions Committee 2006). Climate was cool temperate with short, cool summers and long, cold winters (Strong and Leggat 1992). Mean annual temperature was 0.3 ºC. The 1944-2007 long term average annual precipitation was 471.2 mm, with approximately 322.7 mm of rain and 148.5 cm of snow (Sycnrude Canada 2008). Dominant trees were *Populus tremuloides* Michx. (trembling aspen), *Picea glauca* (Moench) Voss (white spruce) and *Pinus banksiana* Lamb. (jack pine) on upland terrain. Upland soils were mostly gray luvisols on fine textured (loam to clay texture) lacustrine deposits and till; with eutric and dystric brunisols on coarser parent material such as glaciofluvial outwash and eolian sands (Turchenek and Lindsay 1982). Organic soils had developed on poorly drained lowlands and overlay glacial deposits.

The northern Alberta ecosystem classification (Beckingham and Archibald 1996) was used to characterize donor sites, where ecosites are ecological units defined

by hydrologic and nutrient regimes and ecosite phases are subdivisions based on dominant plant species. Donor site trees were harvested 2 to 3 years prior to the survey, thus dominant trees were determined from adjacent undisturbed forests. At Syncrude Aurora North Mine xeric and subxeric to submesic (hereafter submesic) ecosites were present and mesic ecosites occurred at Canadian Natural Resources Horizon Mine (Table 4.1). LFH was developed on coarse textured (sand) soil typical of an orthic eutric brunisol at Aurora North Mine and on fine textured soil typical of an orthic gray luvisol at Horizon Mine (Turchenek and Lindsey 1982).

Three donor sites across Horizon and Aurora North mines were selected based on uniformity of soil type and plant species composition; each donor site represented a different ecosite. In September 2006, six evenly spaced 1 x 1 m quadrats were surveyed for plant species in a 32 m x 32 m area in each ecosite to confirm their differences. Plant species nomenclature followed Moss (1993). At each quadrat, depth of LFH layer was measured by exposing the face of a shallow pit dug with a shovel. Mesic, submesic and xeric donor sites had 21, 15 and 13 species, respectively, and LFH layer depths of 9.1, 5.8 and 3.5 cm, respectively.

4.2.2 Donor Soil Relocation

Prior to mining in October 2006, each donor site was divided into three areas, from which LFH was salvaged at 10, 30 or 60 cm using a D 7 Caterpillar dozer and a Hitachi 500 excavator. At Horizon Mine the excavator mixed each of the three LFH piles separately to simulate mixing that would occur if soils were handled in an operational setting. At Aurora North Mine LFH, for each salvage depth in each ecosite, was dumped into separate piles near the relocation site.

In May 2007, LFH was placed on two substrates at each mine. Substrates were separated by 200 m at Horizon Mine and 400 m at Aurora North Mine. Substrates were mineral soil and peat-mineral mix, the most common materials for reclamation. The mineral component of the substrates was clay loam (fine) at Horizon Mine and sand (coarse texture) at Aurora North Mine. At Horizon Mine

pre-mined land was used for placement due to unavailability of an overburden dump. Prior to placing LFH, the remaining Ae and upper B horizons of the 30 x 30 m placement area was removed with a dozer to clear residual plant propagules. The dozer mixed the remaining B horizon to a 1 m depth with C horizon to simulate a substrate to cap an overburden dump. The peat-mineral substrate placement area was on the edge of a shallow peat-mineral stockpile. The mix was approximately 80:20 peat:mineral composition. Vegetation was removed from the upper 30 to 50 cm of a 50 x 50 m area. Both substrates were located on similar aspects with slope positions of 0.2 to 5%. At Aurora Mine mineral and peat-mineral substrates were placed at 1 m depth over lean oil sands (ore that does not meet the cut off grade of 7 weight % bitumen) dump. Both substrates at Aurora were established on similar aspects and slope positions. Slope was 10 to 20 % on sand substrate and 5 to 10 % on peat-sand substrate. At the time of this research, 1 m of peat-mineral mix (50:50) placed over overburden was standard practice.

Two experiments were established at each mine, each representing a different substrate. For each experiment, ten 1.5 m x 1.5 m plots, nine LFH treatments and one control without LFH, were established in four blocks in a randomized block design. LFH treatments consisted of three salvage depths (10, 30, 60 cm) each placed at three depths (2, 5, 10 cm). At Aurora Mine an additional treatment comparing LFH from submesic and xeric ecosites was establishedthis treatment was applied to all salvage and placement depth combinations. Each block consisted of one replicate of each treatment. Blocks were separated by 4 to 8 m down slope; plots were separated by 2 m buffers. At Horizon Mine each experiment contained 40 experimental units, for a total of 80 experimental units. At Aurora Mine 20 experimental unites were established in each block; each experiment contained 80 experimental units, for a total of 160 experimental units.

Vegetation was assessed in July 2006, 2007 and August 2008. Species density and canopy and ground cover were assessed in 1 m^2 quadrats in experimental unit centers. Nomenclature followed Moss (1993) and species were grouped into native, non native, herbaceous and woody plant groups for analysis. Unidentified plants (2 to 5 per experiment) were excluded from species richness.

4.2.3 Statistical Analyses

One way fixed effects ANOVA was used to determine differences between LFH and control treatments (Zar 1999), ignoring blocking. Significant main effects using one way ANOVA were analyzed using least squares difference (LSD) post hoc test between control and LFH treatments (Carmer and Swanson 1973) for plant group density, canopy cover and species richness. Two way fixed effects ANOVA was used to determine effects of salvage and placement depths, excluding the control, for plant group density, canopy cover and species richness; each experimental site was analysed separately (Zar 1999). Blocking was ignored. Replicates were originally blocked assuming it might explain variation; however, it did not affect vegetation. Thus, to increase power, blocking was excluded in analysis. Significant interaction effects in two way ANOVA were analyzed by comparing LFH treatments using one way ANOVA; if main effects were significant, differences among treatments were analyzed using LSD. Residuals from raw data were tested for normality using the Shapiro-Wilk test and heterogeneity of variances with Levene's test. Data were rank transformed when variances of raw data were heterogeneous. Means and standard errors were used to describe patterns for parameters that did not meet assumptions for homogeneous variances. Analyses were conducted using SPSS 18.0. A p value of ≤ 0.05 was used to determine significant effects for ANOVA and post hoc tests.

4.3 RESULTS AND DISCUSSION

4.3.1 Salvage Depth

Overall, salvage depth affected most response variables, but effect magnitude depended on the variable measured and was influenced by source location (ecosite) of LFH and substrate (Tables 4.2 to 4.20). LFH salvaged from fine textured soil placed on fine textured mineral substrate had the least influence from outside sources of variation; there was little erosion and the substrate did not contribute to plant species beyond those emerging from LFH. The majority of the

response variables had a linear relationship with salvage depth; shallow salvage depths resulted in greater richness, plant density and canopy cover. All groups, except woody plants, had greater densities in year 3 on 10 cm salvage than 30 and 60 cm salvage and significantly more plants for these groups on 30 cm salvage than 60 cm (Table 4.5). There were fewer significant differences between 30 and 60 cm salvages although 30 cm salvage had greater cover (Table 4.15).

On the coarse textured mineral substrate many experimental units had been affected by water erosion in 2007 and by 2008, 25 to 50 % of some plots eroded. In year 1, LFH salvaged at 10 cm and placed at 5 and 10 cm, along with LFH salvaged at 30 cm and placed at 5 cm had the most species (Table 4.2). By 2008, LFH from the submesic ecosite salvaged at 60 cm had significantly lower species richness than LFH salvaged at 10 and 30 cm (Table 4.3). Few plants emerged from LFH on coarse textured mineral substrate in 2006, and salvage depth had no significant effect on density of any plant group (Tables 4.7 and 4.8). In 2008, LFH salvaged at 10 and 30 cm from xeric and submesic ecosites had significantly greater density of several plant groups (Tables 4.9 and 4.10). Salvage depth significantly affected canopy cover on submesic ecosite LFH. The 10 cm salvage had significantly greater cover of total, native, non native and herbaceous plants than 30 and 60 cm salvage on coarse textured mineral substrate (Table 4.19).

The majority of seeds are found in the litter layer and most of the roots are found in the upper 15 cm of the boreal forest surface soil (Moore and Wein 1977, Strong and La Roi 1983, Granström 1986, Hills and Morris 1992, Kramer and Johnson 1997). Therefore, salvaging too deep dilutes the abundant seed and propagule bank. Rokich et al. (2000) reported greater Banksiana species recruitment on a bauxite mine when surface soil was salvaged at 10 cm (254 seedlings 5 m^{-2}) compared to 30 cm (81.33 seedlings 5 m^{-2}). Tacey and Glossop (1980) found stripping the top 5 cm significantly increased plant seedling establishment compared to stripping 40 cm in the jarrah forest. Effects of salvage depth are also applicable to non-vascular plant species, Rochefort et al. (2003) found significantly greater *Sphagnum* capitula establishment from spreading 0 to 10 cm of peatland surface soil than from spreading deeper layers.

Varying salvage depth had a direct impact on organic matter content of the reclamation material, which in turn affects soil nutrient status (Chapter 3). The litter layer in boreal forest soils contains a greater amount of organic matter and macro nutrients than the underlying mineral horizons (Haung and Schoenau 1996, Arocena and Sandborn 1999). Deeper salvage results in a greater proportion of mineral material salvaged. This dilutes the nutrient rich surface organic horizon with less nutrient rich underlying mineral horizon(s). In three (fine textured mineral substrate and coarse textured mineral and peat-mineral mix substrate) of the four experiments, greatest canopy cover was found in LFH treatments with 10 cm salvage. Although soil analysis was not done, the 10 cm salvage treatments contained a higher proportion of the litter layer than the 30 and 60 cm salvages; therefore, it would have greater organic matter content.

There were very few differences between salvage depths using LFH from a xeric ecosite. Surface soil of a xeric ecosite generally has thin LFH, between 0 to 5 cm (Beckingham and Archibald 1996). Average depth of litter of the xeric ecosite in this experiment was 3.5 cm. A 10 cm salvage depth might have been too deep, resulting in few differences among the three salvage depths. Increased density and cover of woody plants in 30 and 60 cm salvages may be attributed to soil water and/or root-soil contact. Although soil water was not measured the 10 cm salvage felt much drier during 2006, when there was low precipitation in spring (April 23.5 mm, May 49 mm) and early summer (June 53.5 mm) (Environment Canada 2012). Under dry conditions slightly darker 10 cm salvage would have warmed and dried out more than deeper salvages. The slight increase of organic matter in the 10 cm salvage could have resulted in a poorer root to soil contact, thereby increasing root mortality in the 10 cm treatment. If either of these scenarios are a cause for reduction in woody plant density and cover, the different response using soil from a submesic ecosite needs to be considered. Soil salvage at 10 cm from the submesic ecosite would have had almost twice the organic matter which could have been sufficient to retain soil water or there was greater propagule density.

Salvage depth had fewer effects on plant density and canopy cover for most plant groups when placed on peat-mineral substrates. Emergence of native and non

native plants from peat-mineral substrate made it difficult to determine treatment effects. The experiment on fine textured peat-mineral substrate was discontinued after 2007, because *Sonchus arvensis* L. (perennial sow thistle) and *Calamagrostis canadensis* (Michx.) Beauv. (marsh reed grass) occupied almost 100 % of the area and litter produced in year 3 made it difficult to find the plots. On fine textured peat-mineral substrate plant density was only measured during 2006, because most species in 2007 were abundant and rhizomatous, making it difficult to count stems. Salvage depth had no effect on plant density for any group (Table 4.6). By year 2, 10 and 30 cm salvages had greater herbaceous cover than 60 cm (Table 4.16). Most woody plants emerged from LFH, except *Rubus idaeus* L. (wild red raspberry) on fine textured peat-mineral substrate. *Rubus idaeus* was found at similar densities on controls and 60 cm salvage placed at 2 cm. The higher cover of *Rubus idaeus* on this treatment is likely a result of mineral soil acting as a barrier for competitive herbaceous species to establish.

Although fewer significant salvage depth effects were detected on coarse textured peat-mineral substrate, shallow salvages 10 and 30 cm) had greater plant response of native plants species. In year 1, on coarse textured peat-mineral substrate, LFH from the submesic ecosite salvaged at 60 cm had significantly lower species richness than LFH salvaged at 10 and 30 cm (Table 4.2). By year 3 salvage depth had no significant effect on species richness. Most plant groups had greater cover on 10 cm salvages placed on coarse textured peat-mineral substrate; however, only native plants was significant (Table 4.20). A significant interaction was found for woody plant cover; further analysis found LFH salvaged at 10 cm and placed at 5 and 10 cm had greater woody plant cover than all other treatments.

4.3.2 Placement Depth

Generally, placement depth affected most response variables, but magnitude of the effect depended on the variable being measured and was influenced by source location (ecosite) of LFH and substrate (Tables 4.2 to 4.20). A placement of only 2 cm of LFH typically resulted in better plant establishment than no LFH

placement. The control on fine textured substrate would not represent subsoil placement at an operational scale, because subsoil is typically salvaged greater than 1.0 m. Placement of LFH even at thin depths would ensure some native species propagules dispersed over the substrate. Further research should be done to determine effectiveness of this method at an operational scale.

Placement depth effects on response variables varied for each experiment. Increases in species richness were more noticeable when LFH was placed on a mineral substrate than on a peat-mineral substrate (Tables 4.2 and 4.3). The experiment using fine textured soil from a mesic ecosite placed on fine textured mineral substrate had a consistent trend of increased species richness, density and canopy cover with increased placement depth for each combination of salvage depth for all plant groups except non native plants. Cover was generally greater on 10 and 5 cm placements using soil salvaged at 10 cm and placed on coarse textured mineral and peat-mineral substrates. Prior research found thicker topsoil replacement depths (> 20 to 30 cm) generally resulted in greater plant cover and/or productivity (Power et al. 1976, McGinnies and Nicholas 1980, Redente et al. 1997). Mackenzie and Naeth (2010) assessed effects of placement depth of two different types of surface soil on a saline-sodic overburden dump. LFH salvaged from an aspen/white spruce developed on a clay loam testured soil, applied at 20 cm resulted in greater cover of all vascular plant groups compared to a 10 cm application. Biondini et al. (1985) and Redente and Hargis (1985) found forbs and shrubs performed best on 15 cm of topsoil, while total production was greater with deeper topsoil. Increased placement depth had no effect or a negative effect on canopy cover of most plant groups when placed on peat-mineral substrate.

Placement depth only had a significant effect on species richness on experiments using LFH salvaged from fine textured mineral soil. Other studies found no effect or lower diversity on deeper topsoil compared to shallow treatments (Redente et al. 1997, Zhang et al. 2001, Bowen et al. 2002). Biondini and Redente (1986) found plant community diversity on a reclaimed area, after 4 years, was also greater with shallow topsoils. 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 use of that particular donor soil. Higher species richness in deeper placements using mesic ecosite soil placed on a mineral substrate could be due to increased available water and soil nutrients. Mackenzie and Naeth (2010) showed deeper placements of a similar soil type contained a greater concentration of available nutrients than shallow placed soil.

Different responses of plants to placement depth on each experiment is likely a result of substrate quality and effect of competing plants establishing from the substrate. Barth and Martin (1984) found that 50, 71 and 100 cm of topsoil was necessary on soil-like generic, sodic and acid spoil, respectively, to maximize forage production. On spoil similar to soil no topsoil was necessary. Peat-mineral substrate is similar to soil-like spoil of Barth and Martin. The substantial increase in organic matter from peat would have increased water and nutrient storage and supply; therefore, plants are not as dependent on the surface soil. Research has found where subsoil characteristics are not limiting the amount and quality of topsoil becomes less important for perennial forages (Schuman and Power 1981). Increased canopy cover of native plants on 5 and 10 cm placements using LFH salvaged from 10 cm on coarse textured peat-mineral substrate is likely a result of added nutrients from LFH. Peat-mineral materials in the Athabasca Oil Sands Region are known to have lower concentrations of phosphorous and potassium than upland surface soils (Chapter 3, MacKenzie and Naeth 2010).

On peat-mineral substrates increased placement depth typically reduced native and non native plant densities. Increased LFH placement depth likely reduced the number of plants emerging from peat-mineral material considering many plants on it emerged from substrate. Increased density on shallow placements could result from increased water at the LFH/substrate interface. Enhanced soil water caused by layering materials of different physical properties is well documented in the oil sands region (Chaikowsky 2003, Burger 2005, Alberta Environment 2006). Under drought conditions, propagules would germinate or emerge better on shallow placements, because propagules near the LFH substrate interface are not buried too deep and are situated in a more hydric environment than if they were elevated too high from the interface.

4.3.3 Ecosite

Ecosites have different species composition due to soil water and nutrient regimes (Beckingham and Archibald 1998). Differences in composition and productivity will result in different ecosites having different abundances and composition of propagule banks. From nutrient and hydrologic status ecosites can be ranked from greatest to least as mesic > submesic > xeric (Beckingham and Archibald 1996). Treatments with greatest species richness and cover were salvaged from a mesic ecosite. Treatments of soil from a submesic ecosite had greater species richness, density and cover of native and woody plants than the xeric ecosite.

Grandin (2001) sampled seed banks along an environmental gradient, finding seed density and species number was positively correlated with soil water. In less productive boreal forests seed banks ar smaller than in nutrient rich forests. More productive boreal forests, on fertile soils, have seed bank densities from 1,273 (Hills and Morris 1992) to 9,108 seeds m^{-2} (MacKenzie and Naeth 2010). Johnson (1975) found no viable seeds in a *Pinus banksiana* soil in Northwest Territories, Canada. Archibold (1979) reported seed densities of 372 seeds m^{-2} from 19 species in a burned mixed wood forest on coarse textured soils in central Canada. Factors such as disturbance history and age of the forest will have a large influence on size and composition of the propagule bank (Hills and Morris 1992).

4.3.4 Substrate

Where the substrate contains an abundant propagule bank of competitive plant species, as seen in the experiment with fine textured peat-mineral substrate, placement of LFH to enhance native plant richness and abundance might not be effective. The experiment established on coarse textured mineral substrate showed that shallow placed soil was highly susceptible to erosion and erosion severity was greater when placed on a substrate that is also susceptible to erosion.

Replacement of topsoil on overburden is a most effective methods of restoring productivity and diversity to mined lands, but depth of placement for maximum production and diversity is affected by spoil or substrate characteristics (Merrill et

al. 1980, Shuman and Power 1981, Depuit 1984). On substrates that have nutrient and water limitations, such as mineral substrates used in this experiment, deeper placements will result in increased production and diversity. Where topsoil or cover soil nutrient content does not greatly exceed that of the substrate, a shallow soil cover may be as effective as a deep one (Hargis and Redente, 1984).

4.4 CONCLUSIONS

Shallow salvage depths (10 cm) had greater species richness, plant density and canopy cover for most groups for most experiments, particularly with LFH salvaged from fine textured soil. LFH salvaged deeper than 30 cm resulted in a significant decrease in plant establishment. When LFH is not limiting or if LFH is to be used to supply a source of seeds it should be salvaged shallow.

Deep placement (10 cm) generally resulted in increased species richness, plant density and canopy cover. LFH placed at depths less than 5 cm on sandy substrates on slopes could be susceptible to high amounts of water erosion. Placement of LFH on substrates or areas that are prone to invasion by competitive herbaceous plants should be avoided, especially for shallow placement depths.

LFH increased species richness, density and canopy cover of total, native, woody, herbaceous and non native plant species when placed on most substrates. Type of substrate LFH was placed on influenced native plant establishment. Most LFH on peat-mineral mix substrates had increased species richness, density and canopy cover for most plant groups; however, substrates containing abundant propagules from competitive, less desired species can out compete more desirable plants from in situ propagules in LFH. Deeper placement of LFH can reduce establishment of undesired plants establishing from insitu propaguels within the substrate.

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Table 4.1. Descriptions of ecosites from which donor materials were procured.

Ecosite Letter	Ecosite Name	Hydrologic Regime	Nutrient Regime	Soils	Dominant Vegetation
D	Low-bush cranberry	Mesic	Medium	Moderately fine to fine texture; glaciolacustrine, till parent materials	Aspen, white spruce, cream colored vetch, bunchberry, hairy wild rye, low bush cranberry, Canada buffalo berry, dewberry, wild sarsaparilla
B	Blueberry	Subxeric to submesic	Poor to medium	Coarse texture; glaciofluvial parent materials	Intermediate between the other two
A	Lichen	Xeric, rapidly drained	Poor to very poor	Coarse texture; eolian, glaciofluvial, fluvial-eolian parent materials; acidic; thin organic layer < 5 cm	Jack pine, bearberry, lichen, bog cranberry, blueberry, labrador tea, wild lily of the valley

Table 4.2. Mean plant species richness in 2007 on LFH treatments salvaged from coarse and fine textured soil and placed on different substrates.

Salvage Depth (cm)	Placement Depth (cm)	Coarse Textured				Fine Textured	
		Substrate Type					
		Mineral		Peat-mineral		Mineral	Peat-mineral
		Ecosite					
		Xeric	Sub-mesic	Xeric	Sub-mesic		
10	2	0.8^{b}	1.3^{b}	2.3	2.3^{A}	1.0^{Ab}	2.1
		(0.3)	(0.3)	(0.8)	(0.9)	(0.4)	(1.0)
	5	0.8^{b}	3.5^{*a}	2.8	3.5^{A}	2.3^{*Ab}	6.3
		(0.5)	(1.2)	(1.8)	(0.6)	(0.3)	(0.8)
	10	2.0^{a}	5.0^{*a}	1.5	4.3^{A}	3.0^{*Aa}	8.3
		(0.8)	(0.4)	(0.5)	(0.9)	(0.6)	(0.3)
30	2	1.3^{b}	0.8^{b}	2.5	1.3^{AB}	0.0^{Ab}	5.3
		(0.6)	(0.3)	(0.6)	(0.9)	(0.0)	(0.9)
	5	1.5^{b}	3.3^{*a}	1.8	2.3^{AB}	1.0^{Ab}	4.8
		(0.3)	(0.6)	(0.9)	(1.0)	(0.4)	(1.9)
	10	2.8^{a}	1.8^{b}	2.3	3.0^{AB}	4.0^{*Aa}	5.5
		(0.3)	(0.9)	(0.5)	(0.0)	(0.8)	(0.6)
60	2	0.5^{b}	0.8^{b}	1.8	2.0^{B}	0.3^{Bb}	6.3
		(0.3)	(0.5)	(0.5)	(1.1)	(0.3)	(0.9)
	5	0.8^{b}	0.3^{b}	0.8	1.5^{B}	0.5^{Bb}	4.5
		(0.5)	(0.3)	(0.5)	(0.3)	(0.3)	(0.5)
	10	2.0^{a}	1.5^{*b}	0.8	1.0^{B}	1.5^{Ba}	3.8
		(0.9)	(0.5)	(0.3)	(0.6)	(0.9)	(0.6)
Control		0.8	0.3	2.3	2.3	0.3	7.3
		(0.5)	(0.3)	(0.6)	(0.9)	(0.3)	(1.4)
p values							
One Way ANOVA							
Treatment		0.087	<0.001	0.661	0.140	<0.001	0.093
Two Way ANOVA							
Salvage depth		0.197	<0.001	0.243	0.024	0.010	0.147
Placement depth		0.006	0.003	0.672	0.099	0.000	0.674
Salvage depth x placement depth		0.999	0.016	0.804	0.784	0.066	0.049

Data are mean and (standard error), n=4. In columns * denotes LFH treatments significantly different from the control. In columns different letters denote significant differences, where upper case letters denote a significant difference between salvage depth and lower case letters denote a significant difference between placement depth or for LFH treatments where interaction effects are significant. Significant differences at $p \leq 0.05$. [2] rank transformed for data analysis.

Table 4.3. Mean plant species richness in 2009 on LFH treatments salvaged from coarse and fine textured soil and placed on different substrates.

Salvage Depth (cm)	Placement Depth (cm)	Coarse Textured				Fine Textured	
		Substrate Type					
		Mineral		Peat-mineral		Mineral	Peat-mineral
		Ecosite					
		Xeric	Sub-mesic	Xeric	Sub-mesic		
10	2	1.5^{b}	3.5^{*A}	5.8	5.3^{b}	5.0^{*Ab}	5.0^{b}
		(0.6)	(0.6)	(1.1)	(1.3)	(0.9)	(0.9)
	5	2.8^{*ab}	5.5^{*A}	6.3	9.0^{*a}	7.5^{*Ab}	6.0^{b}
		(0.9)	(1.3)	(1.3)	(1.1)	(1.3)	(1.7)
	10	1.5^{a}	4.5^{*A}	4.8	7.5^{*a}	11.0^{*Aa}	9.0^{a}
		(0.5)	(1.3)	(0.6)	(0.9)	(1.5)	(1.2)
30	2	1.5^{b}	3.3^{*AB}	5.8	6.8^{*a}	2.5^{Bb}	6.0^{b}
		(0.6)	(0.3)	(1.1)	(0.5)	(0.3)	(1.2)
	5	2.0^{ab}	4.0^{*AB}	5.0	5.8^{b}	3.8^{*Bb}	5.3^{b}
		(0.4)	(0.4)	(0.0)	(0.9)	(0.6)	(1.2)
	10	3.0^{*a}	2.3^{AB}	5.0	5.8^{b}	8.3^{*Ba}	7.8^{a}
		(0.4)	(0.9)	(0.6)	(0.8)	(1.3)	(0.8)
60	2	0.5^{b}	2.5^{*B}	4.5	6.8^{*a}	1.0^{Cb}	4.5^{b}
		(0.3)	(0.6)	(1.5)	(0.9)	(0.7)	(0.6)
	5	1.0^{ab}	3.0^{*B}	3.8	6.5^{*a}	2.0^{Cb}	3.8^{b}
		(0.0)	(0.4)	(1.1)	(0.6)	(0.4)	(0.9)
	10	2.3^{a}	2.0^{B}	3.5	3.0^{b}	3.0^{Ca}	5.5^{a}
		(0.5)	(0.6)	(0.6)	(0.8)	(0.4)	(1.9)
Control		1.3	0.8	4.3	3.8	2.0	4.5
		(0.5)	(0.5)	(0.9)	(1.3)	(0.7)	(0.9)
p values							
One Way ANOVA							
Treatment		0.047	0.010	0.592	0.005	<0.001^{2}	0.351^{2}
Two Way ANOVA							
Salvage depth		0.104	0.016	0.111	0.054	<0.001^{2}	0.103
Placement depth		0.049	0.136	0.525	0.091	<0.001^{2}	0.041
Salvage depth x placement depth		0.155	0.738	0.935	0.012	0.334^{2}	0.791

Data are mean and (standard error), n=4. In columns * denotes LFH treatments significantly different from the control. In columns different letters denote significant differences, where upper case letters denote a significant difference between salvage depth and lower case letters denote a significant difference between placement depth or for LFH treatments where interaction effects are significant. Significant differences at $p \leq 0.05$. ^{2} rank transformed for data analysis.

Table 4.4. Mean density of plant groups established in 2007 on LFH treatments salvaged from fine textured soil placed on fine textured mineral substrate.

Salvage Depth (cm)	Placement Depth (cm)	Total	Native	Non Native	Woody	Herbaceous
10	2	1.0^{Ac}	1.0^{Ac}	0.0	0.0	1.0^{*}
		(0.4)	(0.4)	(0.0)	(0.0)	(0.4)
	5	4.8^{*Ab}	4.5^{*Ab}	0.3	0.3	4.5^{*}
		(1.7)	(1.8)	(0.3)	(0.3)	(1.7)
	10	5.0^{*Aa}	5.0^{*Aa}	0.0	0.3	4.8^{*}
		(1.5)	(1.5)	(0.0)	(0.3)	(1.3)
30	2	0.0^{Ac}	0.0^{Ac}	0.0	0.0	0.0
		(0.0)	(0.0)	(0.0)	(0.0)	(0.0)
	5	1.5^{*Ab}	1.5^{*Ab}	0.0	0.0	1.5^{*}
		(0.5)	(0.5)	(0.0)	(0.0)	(0.5)
	10	9.3^{*Aa}	9.3^{*Aa}	0.0	0.5	8.8^{*}
		(1.5)	(1.5)	(0.0)	(0.3)	(1.4)
60	2	0.3^{Bc}	0.3^{Bc}	0.0	0.3	0.0
		(0.3)	(0.3)	(0.0)	(0.3)	(0.0)
	5	1.3^{*Bb}	1.3^{*Bb}	0.0	0.0	1.3^{*}
		(0.9)	(0.9)	(0.0)	(0.0)	(0.9)
	10	2.3^{*Ba}	2.3^{*Ba}	0.0	0.3	2.0^{*}
		(1.3)	(1.3)	(0.0)	(0.3)	(1.1)
Control		0.3	0.3	0.0	0.3	0.0
		(0.3)	(0.3)	(0.0)	(0.3)	(0.0)
p values						
One Way ANOVA						
Treatment		$<0.001^{2}$	$<0.001^{2}$	0.461^{2}	0.687^{2}	$<0.001^{2}$
Two Way ANOVA						
Salvage depth		0.005^{2}	0.011^{2}	-	-	-
Placement depth		$<0.001^{2}$	$<0.001^{2}$	-	-	-
Salvage depth x placement depth		0.069^{2}	0.115^{2}	-	-	-

Data are mean and (standard error), n=4. In columns * denotes LFH treatments significantly different from the control. In columns different letters denote significant differences, where upper case letters denote a significant difference between salvage depth and lower case letters denote a significant difference between placement depth or for LFH treatments where interaction effects are significant. Significant differences at $p \leq 0.05$. ^{2} rank transformed for data analysis.

Table 4.5. Mean plant density of plant groups established in 2009 on LFH treatments salvaged from fine textured soil placed on a fine textured mineral substrate.

Salvage Depth (cm)	Placement Depth (cm)	Total	Native	Non Native	Woody	Herbaceous
10	2	195.5^{*Ab}	21.5^{*Ac}	174.0^{*A}	0.0	195.5^{*Ab}
		(112.0)	(7.0)	(111.2)	(0.0)	(112.0)
	5	1206.5^{*Aa}	38.5^{*Ab}	1168.0^{*A}	0.8	1205.8^{*Aa}
		(612.5)	(9.7)	(607.2)	(0.5)	(612.6)
	10	276.5^{*Aa}	69.5^{*Aa}	207.0^{*A}	1.3	275.3^{*Aa}
		(92.3)	(12.3)	(86.1)	(0.5)	(92.7)
30	2	7.5^{Bb}	3.3^{Bc}	4.3^{B}	0.0	7.5^{Bb}
		(2.7)	(1.3)	(2.7)	(0.0)	(2.7)
	5	19.5^{*Ba}	13.0^{*Bb}	6.5^{B}	0.0	19.5^{*Ba}
		(4.5)	(3.2)	(2.5)	(0.0)	(4.5)
	10	39.0^{*Ba}	23.0^{*Ba}	16.0^{B}	0.5	38.5^{*Ba}
		(9.5)	(3.4)	(6.1)	(0.5)	(9.1)
60	2	1.8^{Cb}	0.3^{Cc}	1.5^{C}	0.0	1.8^{Cb}
		(1.0)	(0.3)	(0.9)	(0.0)	(1.0)
	5	5.5^{Ca}	3.3^{Cb}	2.3^{C}	0.3	5.3^{Ca}
		(1.8)	(1.3)	(1.0)	(0.3)	(2.1)
	10	8.0^{Ca}	6.3^{*Ca}	1.8^{C}	0.3	7.8^{Ca}
		(3.7)	(3.6)	(0.6)	(0.3)	(3.8)
Control		2.8	1.5	1.3	0.5	2.3^{C}
		(0.8)	(0.6)	(0.6)	(0.5)	(1.0)
p values						
One Way ANOVA						
Treatment		$<0.001^{2}$	$<0.001^{2}$	$<0.001^{2}$	0.159^{2}	$<0.001^{2}$
Two Way ANOVA						
Salvage depth		$<0.001^{2}$	$<0.001^{2}$	$<0.001^{2}$	-	$<0.001^{2}$
Placement depth		0.001^{2}	$<0.001^{2}$	0.438^{2}	-	0.003^{2}
Salvage depth x placement depth		0.376^{2}	0.830^{2}	0.613^{2}	-	0.423^{2}

Data are mean and (standard error), n=4. In columns * denotes LFH treatments significantly different from the control. In columns different letters denote significant differences, where upper case letters denote a significant difference between salvage depth and lower case letters denote a significant difference between placement depth or for LFH treatments where interaction effects are significant. Significant differences at $p \leq 0.05$. [2] rank transformed for data analysis.

Table 4.6. Mean plant density of plant groups established in 2007 on LFH treatments salvaged from fine textured soil placed on a fine textured peat-mineral substrate.

Salvage Depth (cm)	Placement Depth (cm)	Total	Native	Non Native	Woody	Herbaceous
10	2	24.8	23.3	1.5	0.3	24.5
		(14.8)	(14.6)	(1.0)	(0.3)	(14.8)
	5	51.3	37.0	14.3	0.0	51.3
		(22.4)	(25.0)	(12.6)	(0.0)	(22.4)
	10	20.0	18.3	1.8	0.8	19.3
		(2.3)	(2.1)	(1.4)	(0.5)	(2.8)
30	2	34.5	31.0	3.5	0.0	34.5
		(7.8)	(5.6)	(2.5)	(0.0)	(7.8)
	5	38.5	27.8	10.8	0.5	38.0
		(8.6)	(12.9)	(9.8)	(0.5)	(8.5)
	10	23.0	21.8	1.3	0.5	22.5
		(6.0)	(6.5)	(0.9)	(0.5)	(6.3)
60	2	41.3	34.5	6.8	1.8	39.5
		(8.5)	(7.7)	(4.8)	(1.4)	(9.9)
	5	28.5	17.8	10.8	0.3	28.3
		(8.1)	(1.9)	(7.4)	(0.3)	(8.2)
	10	17.3	12.5	4.8	0.3	17.0
		(3.1)	(3.8)	(4.4)	(0.3)	(3.2)
Control		36.3	32.0	4.3	1.7	34.7
		(8.7)	(7.5)	(1.2)	(1.7)	(8.3)
p values						
One Way ANOVA						
Treatment		0.454[2]	0.589[2]	0.693[2]	0.561[2]	0.584[2]
Two Way ANOVA						
Salvage depth		0.552[2]	-	0.558[2]	-	0.530[2]
Placement depth		0.129[2]	-	0.183[2]	-	0.173[2]
Salvage depth x placement depth		0.430[2]	-	0.950[2]	-	0.561[2]

Data are mean and (standard error), n=4. [2] rank transformed for data analysis.

Table 4.7. Mean plant density of plant groups established in 2007 on LFH treatments salvaged from coarse textured soil on a xeric ecosite placed on a coarse textured mineral substrate.

Salvage Depth (cm)	Placement Depth (cm)	Total	Native	Non Native	Woody	Herbaceous
10	2	2.0[b]	1.5[b]	0.5	0.0	2.0[a]
		(1.1)	(1.2)	(0.5)	(0.0)	(1.1)
	5	1.8[b]	1.3[b]	0.5	0.8	1.0[b]
		(1.0)	(0.8)	(0.5)	(0.8)	(1.0)
	10	3.3[a]	3.3[a]	0.0	1.0[*]	2.3[a]
		(1.7)	(1.7)	(0.0)	(0.4)	(1.6)
30	2	2.3[b]	1.0[b]	1.3	0.0	2.3[a]
		(0.9)	(1.0)	(0.8)	(0.0)	(0.9)
	5	3.3[b]	3.3[b]	0.0	1.5	1.8[b]
		(1.7)	(1.7)	(0.0)	(1.5)	(0.5)
	10	10.8[a]	10.8[*a]	0.0	5.0[*]	5.8[a]
		(2.9)	(2.9)	(0.0)	(2.7)	(1.7)
60	2	0.5[b]	0.3[b]	0.3	0.0	0.5[a]
		(0.3)	(0.3)	(0.3)	(0.0)	(0.3)
	5	1.0[b]	1.0[b]	0.0	0.5	0.5[b]
		(0.7)	(0.7)	(0.0)	(0.5)	(0.3)
	10	5.8[a]	5.8[*a]	0.0	1.5	4.3[a]
		(3.6)	(3.6)	(0.0)	(1.2)	(2.4)
Control		0.8	0.1	0.8	0.0	0.8
		(0.5)	(0.1)	(0.5)	(0.0)	(0.5)
p values						
One Way ANOVA						
Treatment		0.075[2]	0.014[2]	0.311[2]	0.006[2]	0.105[2]
Two Way ANOVA						
Salvage depth		0.059[2]	0.153[2]	-	-	0.055[2]
Placement depth		0.029[2]	0.004[2]	-	-	0.046[2]
Salvage depth x placement depth		0.779[2]	0.583[2]	-	-	0.667[2]

Data are mean and (standard error), n=4. In columns* denotes LFH treatments significantly different from the control. In columns different letters denote significant differences between LFH treatments analyzed with two way ANOVA. Significant differences at $p \leq 0.05$. [2] rank transformed for data analysis.

Table 4.8. Mean density of plant groups established in 2007 on LFH treatments salvaged from coarse textured soil on a submesic ecosite placed on coarse textured mineral substrate.

Salvage Depth (cm)	Placement Depth (cm)	Total	Native	Non Native	Woody	Herbaceous
10	2	1.5[*b]	1.5[*b]	0.0	0.0	1.5
		(0.3)	(0.3)	(0.0)	(0.0)	(0.3)
	5	7.8[*a]	5.5[*a]	2.3	1.8	6.0[*]
		(4.1)	(1.9)	(2.3)	(1.2)	(3.1)
	10	14.8[*a]	14.8[*a]	0.0	8.0[*]	6.8[*]
		(2.7)	(2.7)	(0.0)	(2.5)	(0.3)
30	2	1.3[b]	1.0[b]	0.3	0.0	1.3
		(0.6)	(0.7)	(0.3)	(0.0)	(0.6)
	5	6.0[*a]	6.0[*a]	0.0	1.8	4.3[*]
		(2.0)	(2.0)	(0.0)	(1.4)	(0.6)
	10	2.5[*a]	2.5[*a]	0.0	1.0	1.5
		(1.6)	(1.6)	(0.0)	(0.7)	(1.0)
60	2	1.5[b]	0.5[b]	1.0	0.0	1.5
		(1.2)	(0.3)	(1.0)	(0.0)	(1.2)
	5	0.3[a]	0.3[a]	0.0	0.0	0.3
		(0.3)	(0.3)	(0.0)	(0.0)	(0.3)
	10	2.3[*a]	2.3[*a]	0.0	0.8	1.5
		(0.9)	(0.9)	(0.0)	(0.5)	(0.6)
Control		0.3	0.0	0.3	0.0	0.3
		(0.3)	(0.0)	(0.3)	(0.0)	(0.3)
p values						
One Way ANOVA						
Treatment		<0.001[2]	<0.001[2]	0.731[2]	0.001[2]	<0.001[2]
Two Way ANOVA						
Salvage depth		0.083	0.110	-	-	-
Placement depth		0.004	0.002	-	-	-
Salvage depth x placement depth		0.371	0.318	-	-	-

Data are mean and (standard error), n=4. In columns * denotes LFH treatments significantly different from the control. In columns different letters denote significant differences between LFH treatments analyzed with two way ANOVA. Significant differences at $p \leq 0.05$. [2] rank transformed for data analysis.

Table 4.9. Mean density of plant groups established in 2009 on LFH treatments salvaged from coarse textured soil on a xeric ecosite placed on coarse textured mineral substrate.

Salvage Depth (cm)	Placement Depth (cm)	Total	Native	Non Native	Woody	Herbaceous
10	2	2.3	2.0^{Ab}	0.3	0.0	2.3
		(0.9)	(0.8)	(0.3)	(0.0)	(0.9)
	5	5.5	3.3^{Aa}	2.3	1.0*	4.5
		(2.2)	(1.0)	(1.3)	(0.6)	(1.8)
	10	2.3	2.0^{Aa}	0.3	0.3	2.0
		(0.8)	(0.7)	(0.3)	(0.3)	(0.7)
30	2	3.5	1.3^{Ab}	2.3	0.0	3.5
		(1.8)	(0.9)	(1.3)	(0.0)	(1.8)
	5	4.5	3.5^{Aa}	1.0	0.3	4.3
		(1.0)	(0.9)	(0.7)	(0.3)	(1.0)
	10	11.5	11.0^{*Aa}	0.5	7.0*	4.5
		(4.6)	(4.8)	(0.3)	(5.0)	(0.9)
60	2	5.0	0.0^{Bb}	5.0	0.0	5.0
		(3.1)	(0.0)	(3.1)	(0.0)	(3.1)
	5	1.0	0.8^{Ba}	0.3	0.3	0.8
		(0.0)	(0.3)	(0.3)	(0.3)	(0.3)
	10	3.0	2.3^{Ba}	0.8	1.3*	1.8
		(0.8)	(0.5)	(0.5)	(0.6)	(0.3)
Control		2.3	1.5	0.8	0.0	2.3
		(1.0)	(0.6)	(0.5)	(0.0)	(1.0)
p values						
One Way ANOVA						
Treatment		0.118^{2}	0.001^{2}	0.649^{2}	0.001^{2}	0.238^{2}
Two Way ANOVA						
Salvage depth		-	0.002^{2}	0.753^{2}	-	-
Placement depth		-	0.002^{2}	0.619^{2}	-	-
Salvage depth x placement depth		-	0.088^{2}	0.286^{2}	-	-

Data are mean and (standard error), n=4. In columns * denotes LFH treatments significantly different from the control. In columns different letters denote significant differences, where upper case letters denote a significant difference between salvage depth and lower case letters denote a significant difference between placement depth or for LFH treatments where interaction effects are significant. Significant differences at $p \leq 0.05$. ^{2} rank transformed for data analysis.

Table 4.10. Mean density of plant groups established in 2009 on LFH treatments salvaged from coarse textured soil on a submesic ecosite placed on coarse textured mineral substrate.

Salvage Depth (cm)	Placement Depth (cm)	Total	Native	Non Native	Woody	Herbaceous
10	2	16.5^{*A}	6.0	10.5^{*A}	0.0	16.5^{*A}
		(6.8)	(3.2)	(4.2)	(0.0)	(6.8)
	5	31.3^{*A}	15.8*	15.5^{*A}	3.8	27.5^{*A}
		(6.9)	(5.9)	(5.3)	(2.3)	(6.6)
	10	21.5^{*A}	15.0*	6.5^{*A}	2.8	18.8^{*A}
		(4.9)	(5.6)	(2.2)	(1.4)	(4.4)
30	2	19.5^{*B}	2.8	16.8^{*AB}	0.3	19.3^{*B}
		(7.7)	(0.5)	(7.8)	(0.3)	(7.8)
	5	11.5^{*B}	5.0*	6.5^{*AB}	0.5	11.0*^{B}
		(2.8)	(1.1)	(3.0)	(0.3)	(2.8)
	10	4.8^{B}	4.3	0.5^{AB}	1.3	3.5^{B}
		(2.4)	(2.0)	(0.5)	(0.9)	(2.5)
60	2	8.0^{B}	4.5*	3.5^{B}	0.5	7.5^{B}
		(3.5)	(0.9)	(3.2)	(0.5)	(3.8)
	5	5.5^{B}	3.3	2.3^{B}	0.5	5.0^{B}
		(1.2)	(0.9)	(0.6)	(0.5)	(1.5)
	10	5.8^{B}	2.5	3.0^{B}	0.3	5.5^{B} \
		(2.8)	(1.3)	(1.7)	(0.3)	(2.6)
Control		1.5	1.0	0.5	0.0	1.5
		(0.9)	(0.7)	(0.5)	(0.0)	(0.9)
p values						
One Way ANOVA						
Treatment		0.001^{2}	0.029^{2}	0.006^{2}	0.349^{2}	0.002^{2}
Two Way ANOVA						
Salvage depth		0.001^{2}	-	0.019^{2}	-	0.003^{2}
Placement depth		0.419^{2}	-	0.055^{2}	-	0.352^{2}
Salvage depth x placement depth		0.154^{2}	-	0.208^{2}	-	0.181^{2}

Data are mean and (standard error), n=4. In columns * denotes LFH treatments significantly different from the control. In columns different letters denote significant differences between LFH treatments analyzed with two way ANOVA. Significant differences at $p \leq 0.05$. ^{2} rank transformed for data analysis.

Table 4.11. Mean density of plant groups established in 2007 on LFH treatments salvaged from a coarse textured soil on a submesic ecosite placed on coarse textured peat-mineral substrate.

Salvage Depth (cm)	Placement Depth (cm)	Total	Native	Non Native	Woody	Herbaceous
10	2	22.8	0.3	21.8	0.0	22.8
		(19.8)	(0.3)	(20.1)	(0.0)	(19.8)
	5	5.3	4.3	1.0	0.5	4.8
		(3.9)	(3.0)	(1.0)	(0.3)	(3.8)
	10	11.0	1.5	9.5	0.5	10.5
		(9.4)	(0.6)	(9.5)	(0.3)	(9.5)
30	2	2.5	1.3	1.3	0.0	2.5
		(0.6)	(0.6)	(0.6)	(0.0)	(0.6)
	5	6.8	4.3	2.5	0.8	6.0
		(3.8)	(1.9)	(2.5)	(0.5)	(3.5)
	10	3.5	3.3	0.3	2.3*	1.3
		(1.0)	(1.1)	(0.3)	(0.8)	(0.5)
60	2	5.5	3.8	1.0	0.0	5.5
		(2.6)	(2.3)	(0.7)	(0.0)	(2.6)
	5	2.0	0.5	1.5	0.5	1.5
		(1.4)	(0.5)	(1.5)	(0.5)	(1.5)
	10	1.5	1.3	0.0	0.3	1.3
		(0.6)	(0.6)	(0.0)	(0.3)	(0.8)
Control		28.5	1.5	26.8	0.0	28.5
		(20.0)	(0.6)	(20.0)	(0.0)	(20.0)
p values						
One Way ANOVA						
Treatment		0.771[2]	0.309[2]	0.400[2]	0.008[2]	0.497[2]
Two Way ANOVA						
Salvage depth		0.837[2]	0.368[2]	0.832[2]	-	0.856[2]
Placement depth		0.710[2]	0.469[2]	0.248[2]	-	0.295[2]
Salvage depth x placement depth		0.864[2]	0.208[2]	0.943[2]	-	0.817[2]

Data are mean and (standard error), n=4. In columns* denotes LFH treatments significantly different from the control at $p \leq 0.05$. [2] rank transformed for data analysis.

Table 4.12. Mean density of plant groups established in 2009 on LFH treatments salvaged from coarse textured soil on a xeric ecosite placed on coarse textured peat-mineral substrate.

Salvage Depth (cm)	Placement Depth (cm)	Total	Native	Non Native	Woody	Herbaceous
10	2	349.8	111.3	238.5^{Aa}	0.0	349.8
		(196.4)	(75.9)	(126.1)	(0.0)	(196.4)
	5	417.3	48.3	369.0^{Aa}	1.5	415.8
		(281.6)	(29.2)	(254.3)	(1.5)	(280.2)
	10	22.0^{*}	13.3	8.8^{*Ab}	0.8	21.3^{*}
		(5.1)	(4.7)	(4.9)	(0.5)	(4.9)
30	2	57.0	22.5	34.5^{Ba}	0.3	56.8
		(19.7)	(12.0)	(23.5)	(0.3)	(19.8)
	5	33.0	5.8	27.3^{Ba}	1.3	31.8
		(10.3)	(0.3)	(10.1)	(0.3)	(10.2)
	10	15.0^{*}	10.5	4.5^{*Bb}	3.3	11.8^{*}
		(2.3)	(3.8)	(1.7)	(1.2)	(1.5)
60	2	48.5	22.3	26.3^{*Ba}	0.3	48.3
		(22.8)	(11.5)	(15.4)	(0.3)	(22.8)
	5	25.8^{*}	5.3	20.5^{*Ba}	0.8	25.0^{*}
		(5.3)	(2.8)	(3.6)	(0.5)	(5.3)
	10	27.8^{*}	26.5	1.3^{*Bb}	0.3	27.5^{*}
		(13.5)	(13.8)	(0.5)	(0.3)	(13.4)
Control		261.3	156.3	105.0	0.0	261.3
		(169.7)	(148.9)	(42.3)	(0.0)	(169.7)
p values						
One Way ANOVA						
Treatment		0.002^{2}	0.197^{2}	0.001^{2}	0.056^{2}	0.002^{2}
Two Way ANOVA						
Salvage depth		-	-	0.056^{2}	-	-
Placement depth		-	-	0.001^{2}	-	-
Salvage depth x placement depth		-	-	0.789^{2}	-	-

Data are mean and (standard error), n=4. In columns * denotes LFH treatments significantly different from the control. In columns different letters denote significant differences, where upper case letters denote a significant difference between salvage depth and lower case letters denote a significant difference between placement depth or for LFH treatments where interaction effects are significant. Significant differences at $p \leq 0.05$. ^{2} rank transformed for data analysis.

Table 4.13. Mean density of plant groups established in 2009 on LFH treatments salvaged from coarse textured soil on a submesic ecosite placed on coarse textured peat-mineral substrate.

Salvage Depth (cm)	Placement Depth (cm)	Total	Native	Non Native	Woody	Herbaceous
10	2	5.0	1.3[b]	2.8	0.0	5.0
		(2.8)	(0.8)	(2.8)	(0.0)	(2.8)
	5	6.0	5.3[*a]	0.5	1.8[*]	4.3
		(1.7)	(1.6)	(0.3)	(0.5)	(2.0)
	10	10.5	10.3[*a]	0.0	7.0[*]	3.5
		(1.6)	(1.3)	(0.0)	(1.9)	(0.9)
30	2	10.3	1.8[b]	8.5	0.0	10.3
		(6.1)	(1.8)	(5.7)	(0.0)	(6.1)
	5	10.5	2.5[b]	8.0	0.0	10.5
		(4.7)	(1.0)	(4.2)	(0.0)	(4.7)
	10	5.0	5.0[*a]	0.0	2.0[*]	3.0
		(0.8)	(0.8)	(0.0)	(0.4)	(1.1)
60	2	2.8	1.3[b]	1.0	0.3	2.5
		(1.4)	(0.9)	(0.7)	(0.3)	(1.3)
	5	8.0	0.5[b]	7.0	0.0	8.0
		(5.4)	(0.3)	(5.4)	(0.0)	(5.4)
	10	1.5	1.0[b]	0.5	0.3	1.3
		(0.9)	(0.7)	(0.5)	(0.3)	(0.8)
Control		37.0	1.8	34.8	0.0	37.0
		(16.0)	(1.0)	(15.4)	(0.0)	(16.0)
p values						
One Way ANOVA						
Treatment		0.276[2]	0.001[2]	0.071[2]	<0.001[2]	0.681[2]
Two Way ANOVA						
Salvage depth		0.120[2]	<0.001	-	-	0.519[2]
Placement depth		0.534[2]	0.001	-	-	0.477[2]
Salvage depth x placement depth		0.427[2]	0.007	-	-	0.884[2]

Data are mean and (standard error), n=4. In columns * denotes LFH treatments significantly different from the control. In columns different letters denote significant differences between LFH treatments analyzed with two way ANOVA. Significant differences at $p \leq 0.05$. 2 rank transformed for data analysis.

Table 4.14. Mean density of plant groups established in 2009 on LFH treatments salvaged from coarse textured soil on a submesic ecosite placed on coarse textured peat-mineral substrate.

Salvage Depth (cm)	Placement Depth (cm)	Total	Native	Non Native	Woody	Herbaceous
10	2	184.5^{Aa}	35.8	148.8^{a}	0.3^{c}	184.3^{Aa}
		(91.9)	(16.3)	(90.0)	(0.3)	(91.8)
	5	257.8^{Aa}	75.3	182.5^{a}	5.8^{*a}	252.0^{Aa}
		(63.3)	(46.0)	(86.4)	(0.9)	(63.5)
	10	46.0^{Ab}	27.3	18.8^{b}	8.0^{*a}	38.0^{Ab}
		(13.0)	(8.9)	(17.1)	(1.8)	(14.4)
30	2	419.8^{Ba}	96.0	323.8^{a}	0.8^{c}	419.0^{Ba}
		(363.5)	(70.6)	(293.6)	(0.8)	(363.7)
	5	82.3^{Ba}	38.0	44.3^{a}	2.3^{*b}	80.0^{Ba}
		(29.7)	(17.1)	(21.3)	(0.6)	(30.0)
	10	19.0^{*Bb}	12.3	6.8^{b}	1.5^{*b}	17.5^{*Bb}
		(5.0)	(4.0)	(1.8)	(0.6)	(4.6)
60	2	95.3^{Ba}	47.0	48.3^{a}	2.5^{*b}	92.8^{Ba}
		(25.8)	(36.4)	(20.3)	(1.6)	(24.7)
	5	66.5^{Ba}	22.5	44.0^{a}	0.3^{c}	66.3^{Ba}
		(31.9)	(5.6)	(36.5)	(0.3)	(31.9)
	10	12.0^{*Bb}	9.8	2.3^{b}	1.0^{*b}	11.0^{*Bb}
		(7.3)	(7.5)	(1.6)	(0.4)	(7.0)
Control		150.0	66.0	84.0	0.0	150.0
		(58.8)	(33.4)	(46.0)	(0.0)	(58.8)
p values						
One Way ANOVA						
Treatment		0.004^{2}	0.504^{2}	0.287^{2}	<0.001^{2}	0.003^{2}
Two Way ANOVA						
Salvage depth		0.029^{2}	0.213^{2}	0.605^{2}	0.005^{2}	0.035^{2}
Placement depth		<0.001^{2}	0.165^{2}	0.013^{2}	0.009^{2}	<0.001^{2}
Salvage depth x placement depth		0.421^{2}	0.828^{2}	0.871^{2}	<0.001^{2}	0.545^{2}

Data are mean and (standard error), n=4. In columns * denotes LFH treatments significantly different from the control. In columns different letters denote significant differences, where upper case letters denote a significant difference between salvage depth and lower case letters denote a significant difference between placement depth or for LFH treatments where interaction effects are significant. Significant differences at $p \leq 0.05$. ^{2} rank transformed for data analysis.

Table 4.15. Mean canopy cover of plant groups established in 2009 on LFH treatments salvaged from fine textured soil placed on a fine textured mineral substrate.

Salvage Depth (cm)	Placement Depth (cm)	Total	Native	Non Native	Woody	Herbaceous
10	2	24.20^{*Ab}	21.65^{*Ab}	2.55^{A}	0.00	24.20^{*Ac}
		(8.08)	(8.27)	(1.24)	(0.00)	(8.08)
	5	43.36^{*Aa}	23.61^{*Ab}	19.75^{*A}	0.40	42.96^{*Ab}
		(5.97)	(6.76)	(9.48)	(0.24)	(5.83)
	10	60.66^{*Aa}	56.78^{*Aa}	3.88^{*A}	0.93	59.74^{*Aa}
		(8.24)	(6.84)	(1.63)	(0.70)	(8.71)
30	2	5.03^{Bb}	4.08^{Bb}	0.95^{B}	0.00	5.03^{Bc}
		(2.04)	(2.19)	(0.79)	(0.00)	(2.04)
	5	11.28^{*Ba}	10.45^{*Bb}	0.83^{B}	0.00	11.28^{*Bb}
		(3.50)	(3.75)	(0.49)	(0.00)	(3.50)
	10	20.48^{*Ba}	19.85^{*Ba}	0.63^{B}	0.25	20.23^{*Ba}
		(3.18)	(3.52)	(0.46)	(0.25)	(2.99)
60	2	0.13^{Bb}	0.03^{Bb}	0.10^{B}	0.00	0.13^{Cc}
		(0.08)	(0.03)	(0.07)	(0.00)	(0.08)
	5	8.10^{Ba}	7.90^{Bb}	0.20^{B}	0.08	8.03^{Cb}
		(3.05)	(3.00)	(0.08)	(0.08)	(3.11)
	10	13.75^{*Ba}	12.85^{*Ba}	0.90^{B}	0.08	13.68^{*Ca}
		(4.07)	(4.39)	(0.71)	(0.08)	(4.13)
Control		2.53	2.10	0.43^{B}	0.75	1.78
		(0.56)	(0.76)	(0.22)	(0.75)	(0.80)
p values						
One Way ANOVA						
Treatment		<0.001^{2}	<0.001^{2}	0.004^{2}	0.194^{2}	<0.001^{2}
Two Way ANOVA						
Salvage depth		<0.001	<0.001	<0.001^{2}	-	<0.001^{2}
Placement depth		<0.001	<0.001	0.548^{2}	-	<0.001^{2}
Salvage depth x placement depth		0.187	0.056	0.814^{2}	-	0.931^{2}

Data are mean and (standard error), n=4. In columns * denotes LFH treatments significantly different from the control. In columns different letters denote significant differences, where upper case letters denote a significant difference between salvage depth and lower case letters denote a significant difference between placement depth or for LFH treatments where interaction effects are significant. Significant differences at $p \leq 0.05$. ^{2} rank transformed for data analysis.

Table 4.16. Mean canopy cover of plant groups established in 2008 on LFH treatments salvaged from fine textured soil placed on a fine textured peat-mineral substrate.

Salvage Depth (cm)	Placement Depth (cm)	Total	Native	Non Native	Woody	Herbaceous
10	2	65.43[b]	45.18	20.25	0.25	65.18[AB]
		(10.60)	(4.02)	(8.37)	(0.25)	(10.81)
	5	74.70[a]	39.45	35.25	0.45	74.25[AB]
		(18.11)	(21.39)	(18.75)	(0.45)	(18.51)
	10	86.20[a]	43.20	43.00	0.50	85.70[AB]
		(6.94)	(7.48)	(14.29)	(0.50)	(6.66)
30	2	89.14[a]	53.75	35.39	2.50	86.64[A]
		(7.91)	(15.62)	(20.80)	(2.50)	(9.52)
	5	99.20[a]	47.55	51.65	0.15	99.05[A]
		(6.04)	(20.99)	(25.12)	(0.15)	(6.17)
	10	65.95[b]	52.58	13.38	0.05	65.90[A]
		(10.32)	(11.94)	(3.18)	(0.05)	(10.35)
60	2	91.25[a]	45.75	45.50	20.00	71.25[B]
		(14.70)	(6.22)	(11.59)	(12.25)	(22.90)
	5	50.48[b]	22.73	27.75	0.00	50.48[B]
		(11.29)	(15.34)	(7.70)	(0.00)	(11.29)
	10	45.24[b]	13.49	31.75	2.00	43.24[B]
		(9.79)	(5.96)	(13.46)	(2.00)	(10.24)
Control		77.19	57.94	19.25	0.00	77.19
		(18.21)	(16.34)	(4.96)	(0.00)	(18.21)
p values						
One Way ANOVA						
Treatment		0.070[2]	0.393[2]	0.730[2]	0.852[2]	0.197[2]
Two Way ANOVA						
Salvage depth		0.065	0.121[2]	0.548[2]	0.946[2]	0.031
Placement depth		0.229	0.321[2]	0.868[2]	0.541[2]	0.585
Salvage depth x placement depth		0.024	0.719[2]	0.488[2]	0.744[2]	0.223

Data are mean and (standard error), n=4. In columns * denotes LFH treatments significantly different from the control. In columns different letters denote significant differences, where upper case letters denote a significant difference between salvage depth and lower case letters denote a significant difference between placement depth or for LFH treatments where interaction effects are significant. Significant differences at $p \leq 0.05$. [2] rank transformed for data analysis.

Table 4.17. Mean canopy cover of plant groups established in 2009 on LFH treatments salvaged from coarse textured soil on a xeric ecosite placed on coarse textured mineral substrate.

Salvage Depth (cm)	Placement Depth (cm)	Total	Native	Non Native	Woody	Herbaceous
10	2	0.61[b]	0.60[c]	0.00	0.00	0.61[ABb]
		(0.53)	(0.53)	(0.00)	(0.00)	(0.53)
	5	1.04[ab]	0.77[b]	0.28	0.03	1.01[ABb]
		(0.27)	(0.24)	(0.13)	(0.02)	(0.24)
	10	1.45[a]	1.43[a]	0.03	0.00	1.45[ABa]
		(0.49)	(0.48)	(0.03)	(0.00)	(0.49)
30	2	1.33[b]	1.28[c]	0.05	0.00	1.33[Ab]
		(1.26)	(1.24)	(0.03)	(0.00)	(1.26)
	5	2.65[ab]	2.60[b]	0.05	0.03	2.63[Ab]
		(1.53)	(1.51)	(0.03)	(0.03)	(1.54)
	10	6.23[*a]	6.13[*a]	0.10	0.75[*]	5.48[*Aa]
		(2.02)	(2.06)	(0.06)	(0.43)	(2.07)
60	2	0.30[b]	0.00[c]	0.30	0.00	0.30[Bb]
		(0.24)	(0.00)	(0.24)	(0.00)	(0.24)
	5	1.10[ab]	1.08[b]	0.03	1.00	0.10[Bb]
		(0.97)	(0.98)	(0.03)	(1.00)	(0.04)
	10	4.73[*a]	4.58[*a]	0.15	3.08[*]	1.65[Ba]
		(1.74)	(1.79)	(0.10)	(1.74)	(0.56)
Control		1.43	1.33	0.10	0.00	1.43
		(1.23)	(1.23)	(0.07)	(0.00)	(1.23)
p values						
One Way ANOVA						
Treatment		0.040[2]	0.007[2]	0.695[2]	0.001[2]	0.034[2]
Two Way ANOVA						
Salvage depth		0.231[2]	0.152[2]	-	-	0.048[2]
Placement depth		0.002[2]	<0.001[2]	-	-	0.005[2]
Salvage depth x placement depth		0.490[2]	0.294[2]	-	-	0.406[2]

Data are mean and (standard error), n=4. In columns * denotes LFH treatments significantly different from the control. In columns different letters denote significant differences, where upper case letters denote a significant difference between salvage depth and lower case letters denote a significant difference between placement depth or for LFH treatments where interaction effects are significant. Significant differences at $p \leq 0.05$. [2] rank transformed for data analysis.

Table 4.18. Mean canopy cover of plant groups established in 2009 on LFH treatments salvaged from coarse textured soil on a xeric ecosite placed on coarse textured peat-mineral substrate.

Salvage Depth (cm)	Placement Depth (cm)	Total	Native	Non Native	Woody	Herbaceous
10	2	12.13	6.10	6.03	0.00	12.13
		(4.11)	(2.55)	(1.57)	(0.00)	(4.11)
	5	13.16	5.43	7.73	0.53	12.63
		(3.87)	(1.32)	(3.00)	(0.53)	(3.50)
	10	14.41	11.93	2.48	0.01	14.40
		(4.83)	(5.06)	(1.90)	(0.00)	(4.83)
30	2	11.99	11.16	0.83	0.00	11.99
		(6.10)	(6.34)	(0.42)	(0.00)	(6.10)
	5	6.66	2.36	4.30	0.81	5.85
		(2.73)	(0.98)	(2.30)	(0.73)	(3.01)
	10	3.28	1.75	1.53	0.20	3.08
		(1.16)	(0.80)	(0.68)	(0.08)	(1.17)
60	2	11.32	7.75	3.57	0.03	11.29
		(4.11)	(3.24)	(2.58)	(0.03)	(4.12)
	5	8.21	0.43	7.78	0.08	8.13
		(1.49)	(0.30)	(1.33)	(0.05)	(1.53)
	10	11.40	11.10	0.30*	0.30	11.10
		(7.78)	(7.56)	(0.23)	(0.30)	(7.81)
Control		5.51	3.10	2.40	0.00	5.51
		(1.78)	(1.92)	(0.55)	(0.00)	(1.78)
p values						
One Way ANOVA						
Treatment		0.596[2]	0.113[2]	0.011[2]	0.075[2]	0.566[2]
Two Way ANOVA						
Salvage depth		0.179[2]	0.222[2]	-	0.093[2]	0.150[2]
Placement depth		0.604[2]	0.096[2]	-	0.062[2]	0.608[2]
Salvage depth x placement depth		0.903[2]	0.140[2]	-	0.735[2]	0.901[2]

Data are mean and (standard error), n=4. In columns * denotes LFH treatments significantly different from the control. In columns different letters denote significant differences, where upper case letters denote a significant difference between salvage depth and lower case letters denote a significant difference between placement depth or for LFH treatments where interaction effects are significant. Significant differences at $p \leq 0.05$. [2] rank transformed for data analysis.

Table 4.19. Mean canopy cover of plant groups established in 2009 on LFH treatments salvaged from coarse textured soil on a submesic ecosite placed on coarse textured mineral substrate.

Salvage Depth (cm)	Placement Depth (cm)	Total	Native	Non Native	Woody	Herbaceous
10	2	6.53^{*A}	5.03^{*A}	1.50*	0.00	6.53^{*A}
		(1.22)	(1.51)	(0.46)	(0.00)	(1.22)
	5	14.08^{*A}	12.56^{*A}	1.53*	3.08	11.00^{*A}
		(2.01)	(1.80)	(0.53)	(2.12)	(2.69)
	10	18.20^{*A}	12.95^{*A}	5.25*	0.53	17.68^{*A}
		(3.01)	(5.50)	(3.42)	(0.28)	(3.18)
30	2	3.59^{*B}	1.93^{B}	1.65*	0.08	3.51^{*B}
		(2.04)	(1.69)	(0.99)	(0.08)	(2.07)
	5	7.06^{*B}	6.30^{*B}	0.76	0.28	6.79^{*B}
		(1.51)	(1.86)	(0.47)	(0.24)	(1.27)
	10	2.18^{B}	2.15^{B}	0.03	0.10	2.08^{B}
		(1.70)	(1.67)	(0.03)	(0.07)	(1.72)
60	2	1.92^{*B}	1.67^{*B}	0.25	0.03	1.89^{B}
		(0.71)	(0.59)	(0.25)	(0.03)	(0.73)
	5	1.70^{B}	1.53^{B}	0.18	0.20	1.50^{B}
		(1.18)	(1.17)	(0.05)	(0.20)	(1.23)
	10	1.13^{B}	0.70^{B}	0.38	0.03	1.10^{B}
		(0.52)	(0.37)	(0.24)	(0.03)	(0.49)
Control		0.26	0.25	0.00	0.00	0.26^{B}
		(0.25)	(0.25)	(0.00)	(0.00)	(0.25)
p values						
One Way ANOVA						
Treatment		<0.001^{2}	0.001^{2}	0.006^{2}	0.355^{2}	<0.001^{2}
Two Way ANOVA						
Salvage depth		<0.001^{2}	<0.001	0.004^{2}	0.451^{2}	<0.001^{2}
Placement depth		0.121^{2}	0.124	0.323^{2}	0.213^{2}	0.317^{2}
Salvage depth x placement depth		0.086^{2}	0.260	0.356^{2}	0.603^{2}	0.082^{2}

Data are mean and (standard error), n=4. In columns * denotes LFH treatments significantly different from the control. In columns different letters denote significant differences, where upper case letters denote a significant difference between salvage depth and lower case letters denote a significant difference between placement depth or for LFH treatments where interaction effects are significant. Significant differences at $p \leq 0.05$. ^{2} rank transformed for data analysis.

Table 4.20. Mean canopy cover of plant groups established in 2009 on LFH treatments salvaged from coarse textured soil on a subxeric ecosite placed on coarse textured peat-mineral substrate.

Salvage Depth (cm)	Placement Depth (cm)	Total	Native	Non Native	Woody	Herbaceous
10	2	10.06	3.48^{Ab}	6.58	0.05^{b}	10.01
		(2.00)	(1.73)	(3.16)	(0.05)	(2.01)
	5	32.06^{*}	26.25^{*Aa}	5.80	3.80^{*a}	28.26
		(11.72)	(13.47)	(3.47)	(1.83)	(12.71)
	10	22.83	21.18^{*Aab}	1.65	4.55^{*a}	18.28
		(9.73)	(10.28)	(1.45)	(2.96)	(11.12)
30	2	10.14	3.13^{ABb}	7.00	0.05^{b}	10.08
		(4.74)	(1.10)	(3.81)	(0.05)	(4.77)
	5	16.25	14.60^{ABa}	1.65	0.18^{*b}	16.08
		(9.07)	(9.60)	(0.60)	(0.05)	(9.09)
	10	9.48	8.00^{*ABab}	1.48	0.40^{*b}	9.08
		(3.00)	(2.81)	(0.57)	(0.27)	(2.88)
60	2	5.86	3.78^{Bb}	2.08	0.83^{*b}	5.03
		(0.66)	(1.29)	(0.83)	(0.76)	(1.02)
	5	9.49	5.41^{Ba}	4.08	0.05^{b}	9.44
		(2.09)	(1.44)	(3.01)	(0.05)	(2.13)
	10	2.25	1.33^{Bab}	0.93	0.58^{*b}	1.68
		(1.49)	(0.69)	(0.86)	(0.48)	(1.03)
Control		8.68	1.75	6.93	0.00	8.68
		(4.77)	(0.94)	(4.46)	(0.00)	(4.77)
p values						
One Way ANOVA						
Treatment		0.017^{2}	0.002^{2}	0.836^{2}	$<0.001^{2}$	0.101^{2}
Two Way ANOVA						
Salvage depth		-	0.008^{2}	0.838^{2}	0.021^{2}	-
Placement depth		-	0.019^{2}	0.217^{2}	0.015^{2}	-
Salvage depth x placement depth		-	0.083^{2}	0.910^{2}	0.009^{2}	-

Data are mean and (standard error), n=4. In columns * denotes LFH treatments significantly different from the control. In columns different letters denote significant differences, where upper case letters denote a significant difference between salvage depth and lower case letters denote a significant difference between placement depth or for LFH treatments where interaction effects are significant. Significant differences at $p \leq 0.05$. [2] rank transformed for data analysis.

CHAPTER V
EFFECT OF BOREAL FOREST TOPSOIL (LFH) STORAGE ON NATIVE SEED VIABILITY AND GERMINATION AND SOIL CHEMISTRY, TEMPERATURE, WATER AND ATMOSPHERE

5.1 INTRODUCTION

Operators of mines and other energy exploration and development companies in many jurisdictions are required to reclaim disturbances, which often means replacing salvaged topsoil. In Alberta, these disturbances in boreal forest must be reclaimed to diverse, self-sustaining plant communities similar the surrounding region (Alberta Environmental Protection 1998, Fung and Macyk 2000). Recent research on boreal forest topsoil (LFH, LFH mixed with upper mineral horizon(s)) has provided industry with a means to use a local diverse seed source and fertile surface soil to meet their reclamation requirements (MacKenzie and Naeth 2007, Mackenzie and Naeth 2010). Salvaging, storing and replacing forest topsoil is now considered a best practice in Alberta (Alberta Environment and Water 2012). Research has focused on effects of salvage and replacement depth of forest topsoil on plant community establishment; however, effects of storage on soil properties have not been well studied. Previous studies investigated effects of stockpiling in tropical, arid and prairie environments, but few have focused on boreal forest.

Negative impacts of topsoil storage on soil physical, biological and chemical properties are recognized (Dougal 1950, Widdowson et al. 1982, Stark and Redente 1987). Examples of soil quality changes include reduced organic matter, nitrogen, microbial activity, mycorrhizal density, earthworm populations and nutrient cycling rates (Rives et al. 1980, Gould and Liberta 1981). Visser et al. (1984) found immediate losses of organic carbon in 0 to 15 cm and 100 to 150 cm layers of a stockpiled, prairie topsoil in Canada. Organic carbon was reduced by 28 % at 0 to 15 cm and 12.6 % at 100 to 150 cm depths.

The magnitude of soil quality reduction depends on texture and depth. Greater losses of organic matter were found in sandy soil (85 %) than clay soil (32 %)

(Abul-Kareem and McRae 1984). Anderson et al. (1988) found total nitrogen decreased 100 mg kg^{-1} on stockpile surfaces after 30 months and decreased deeper in the stockpile. Anaerobic conditions have been detected deep in stockpiles (Widdowson et al. 1982). Soil gases in stockpiles, such as carbon dioxide and ethylene increase with depth and clay content; methane and nitrogen were high even at shallow depths (Abul-Kareem and McRae 1984). Abul-Kareem and McRae (1984) found dramatic increases in extractable manganese, ferrous iron and ammonium nitrogen with increasing depth, with greater changes in clay soil than sandy soil. For example, in a clay textured stockpile, ferrous iron increased from 72 ug g^{-1} at 40 to 50 cm to 18,100 ug g^{-1} at 100 to 150 cm and in a sand textured stockpile iron increased from 371 ug g^{-1} to 4,800 ug g^{-1} at 100 to 150 cm.

In Alberta, Canada, Kong et al. (1980) found temperature in stored peat stockpiles fluctuated between 0 and 20 °C throughout one year in the upper 50 cm; at greater depths soil temperature remained fairly constant below 10 °C. A study in Australia (Anderson et al. 1988) found only small difference in soil temperature between wet and dry stockpiles, temperatures fluctuated (6 to 37 °C) with seasonal changes in the upper 100 cm, but remained constant (21 to 28 °C) below.

Seed viability in stockpiles decreases with storage time and can occur quickly. Rokich et al. (2000) found a significant decrease of 12 *Banksia* woodland species after 1 month of storage; depth and storage time had little effect on viability. Another Australian study showed the seed bank decreased 3 to 13 % in 10 to 13 months (Koch et al. 1996). Dickie et al. (1988) studied 4 month and 4 year old stockpiles in Derbyshire, reporting a large reduction in viable propagules for most species in older piles at all depths. Tacey and Glossop (1980) found significant decreases in establishment when using stockpiles as an inoculum on reclaimed Australian sites. Various factors affect seed longevity in stockpiles. Seeds can be lost via in situ germination, microbial pathogens and senescence (Harris and Birch 1987). Seeds and roots may be physically damaged in stockpiling.

Stockpiling effects can be different in cold environments like boreal forest than in warmer climates. Roots are a major contributor to secondary succession in the

boreal (Whittle et al. 1997). No attempts have been made to assess root viability in stockpiles. Effects of stockpile size on viability of propagules and soil quality has not been studied. Our research assessed storage methods on boreal forest surface soil to determine effects on soil chemical and physical properties, native seed viability and germination and root viability and emergence. Factors were topsoil stockpiling length, stockpile size, season of construction and soil texture.

5.2 MATERIAL AND METHODS

5.2.1 Research Site Descriptions

Three areas near active oil sands mines were selected to construct stockpiles; Syncrude Canada Ltd. Aurora North mine (latitude 57^{o} 21' N, longitude 111^{o} 31' W), the Shell Albian Sands Muskeg River mine (latitude 57^{o} 16' N, longitude 111^{o} 27' W) and the Canadian Natural Resources Ltd. Horizon mine (latitude 57^{o} 21' N, longitude 111^{o} 48' W) in the central mixed wood subregion of the boreal natural region (Natural Regions Committee 2006). Climate was cool temperate with short, cool summers and long, cold winters (Strong and Leggat 1992). Mean annual temperature was 0.3 ºC (Sycnrude Canada 2008). The 1944 to 2007 long term average annual precipitation was 471.2 mm, with approximately 322.7 mm of rain and 148.5 cm of snow (Sycnrude Canda 2008).

Soils in the research area are orthic gray luvisols and eluviated and orthic eutric brunisols (Turchenek and Lindsey 1982). Pre-disturbance vegetation was representative of the mixed wood boreal forest for each soil. Undisturbed orthic gray luvisols typically support *Picea glauca* (Monech) Voss (white spruce) and *Populus tremuloides* Michx. (trembling aspen) forests and orthic eutric brunisols support *Pinus banksiana* Lamb. (jack pine) and *Populus tremuloides* Michx.

5.2.2 Seed and Root Collection and Processing

Seeds of 27 native boreal plant species from unmined areas around the mines were hand collected when ripe between July and September 2006. Species

nomenclature follows Moss (1993). Forb species were *Anemone multifida* Poir. (cut leaved anemone), *Anemone patens* L. (prairie crocus), *Aralia nudicaulis* L. (wild sarsaparilla), *Cornus canadensis* L. (bunchberry), *Dracocephalum parviflorum* Nutt. (American dragonhead), *Fragaria virginiana* Duchesne (wild strawberry), *Geranium bicknellii* Britt. (northern cranesbill), *Potentilla tridentata* Ait. (three toothed cinquefoil), *Rubus pubescens* Raf. (dewberry) and *Vicia americana* Muhl. (American vetch). Grass species were *Agropyron trachycaulum* var. trachycaulum (Cassidy) Malte (slender wheat grass), *Bromus ciliatus* L. (fringed brome), *Elymus innovatus* Beal. (hairy wild rye) and *Oryzopsis pungens* (Torr.) A.S. Hitchc (jack pine rice grass). Shrub species were *Alnus crispa* (Ait.) Pursh (green alder), *Arctostaphylos uva-ursi* (L.) Spreng. (kinnickinick), *Prunus pensylvanica* (L.f) (pin cherry), *Ribes hudsonianum* Richards. (wild black currant), *Rosa acicularis* Lindl. (prickly rose), *Rubus idaeus* L. (wild red raspberry), *Shepherdia canadensis* (L.) Nutt. (Canada buffalo berry), *Vaccinium myrtilloides* Michx (blueberry), *Vaccinium vitis-idea* (L.) Nutt. (bog cranberry) and *Viburnum edule* (Michx.) Raf. (low bush cranberry). One sedge (*Carex aenea* Fern. (bronze sedge)), one lily (*Maianthemum canadense* Desf. (wild lily of the valley) and one tree (*Pinus banksiana* Lamb. (jack pine)) was included. Roots from *Maianthemum canadense*, *Vaccinium myrtilloides* and *Arctostaphylos uva-ursi* were hand dug. These plant species were broadly representative, including key families, life forms, dormancy mechanisms and seed sizes.

All seeds were air dried at room temperature with a fan blowing on a bench for two weeks before placement into sachets. Berries of *Vaccinium myrtilloides*, *Vaccinium vitis-idea*, *Ribes hudsonianum*, *Rubus idaeus*, *Rosa acicularis*, *Fragaria virginiana* and *Rubus pubescens* were macerated with a blender, then screened and cleaned with tap water to prevent viability loss from fungi. Macerated seeds were air dried with the aid of a fan for two weeks after processing. After drying, seeds were stored in sealed mason jars in the dark at room temperature. Roots from *Maianthemum canadense*, *Vaccinium myrtilloides* and *Arctostaphylos uva-ursi* were harvested one week prior to installation in the stockpile and stored at 4 ºC in a refrigerator at the University of Alberta.

Four replicates of 25 seeds from each species were used to test each of viability and germination. A total of 100 seeds were tested prior to installation in stockpiles and 100 seeds following stockpiling. Prior to installation in stockpiles, 50 seeds of each species were placed in individual 5 x 8 cm permeable, black, mesh, sewn bags, made of 100 % nylon, which allowed seeds to experience ambient hydrologic and temperature conditions in the stockpiles while permitting recovery. One teaspoon of heat sterilized sand was included in each bag to evenly distribute seeds and provide a medium for water and nutrient flow. Three species received ¼ teaspoon of sand (*Fragaria virginiana*, *Vaccinium vitis-idea*, *Vaccinium myrtilloides*) to help retrieve small seeds once extracted. The ends of seed bags were sealed with thermoplastic adhesive. A 30 x 50 cm permeable sachet of sewn polyethylene mesh contained 26 seed bags each with one species, which allowed propagules to experience ambient hydrologic and temperature conditions in the stockpiles while permitting recovery. Two jack pine cones and five root cuttings from each of *Maianthemum canadense*, *Vaccinium myrtilloides* and *Arctostaphylos uva-ursi* were placed in select sachets. *Maianthemum canadense* and *Vaccinium myrtilloides* were cut into 10 cm segments and *Arctostaphylos uva-ursi* into 15 cm segments. A total of 144 sachets were used, 20 in each large stockpile and 16 in each small stockpile.

5.2.3 Stockpile Construction and Instrumentation

Four replicates each of large (6 m height) and small (3 m height) stockpiles were built at three mine sites. Two replicates were built at Syncrude Aurora North, one at Shell Albian Muskeg River and one at Canadian Natural Resources Ltd. Horizon. Three replicates were of coarse textured (sand) soil (orthic and eluviated eutric brunisol) and one from fine textured (clay loam) soil (orthic gray luvisol) using available material. Stockpile construction began October 2006 at Horizon and Aurora North mines; the other in January 2007 due to operational logistics.

Large stockpiles were big enough to accommodate operationally sized equipment; dimensions were 36 x 20 m at the base and 6 m high. Small stockpiles were 4 x

15 m at the base and 3 m high. Small stockpiles simulated windrows found throughout the region. Construction of each replicate involved salvaging topsoil 15 cm deep into windrows with crawler tractors and large tracked excavators over 4 ha of logged forest at each mine site per set of large and small stockpiles. The windrowed soil was hauled to placement areas and stockpiles were constructed in 1 m lifts to accommodate seed placement and instrument installation.

Sachets and soil water and temperature probes were installed in all stockpiles during construction. Sachets were installed in large stockpiles at 6, 4, 2, 1 and 0.05 m depths. Sachets containing jack pine cones and root cuttings were placed at 6, 2 and 0.05 m depths. Soil probes were installed at 6, 4, 2, 1, 0.6 and 0.3 m depths. In small stockpiles, sachets were installed at 3, 2, 1 and 0.05 m depths, sachets with jack pine and root cuttings were installed at 3 and 0.05 m depths. Soil probes were installed at 3, 1, 0.6 and 0.3 m depths. A total of 40 soil probes for soil water and 40 for soil temperature were installed; 5 of each were installed in each large stockpile and 4 in each small stockpile.

To aid in extraction, sachets were attached to 1/16 inch aircraft cable and orange snow fence. Four sets of sachets were placed at each depth and were spread approximately 4 to 5 m apart in the centre of each stockpile to allow for multiple years of monitoring. The spacing was sufficient in distance to prevent effects from outside air affecting in situ sachets during extractions.

Campbell Scientific Inc. (CSI) Model 107B soil and water temperature probes and CSI Model CS616 soil volumetric water content reflectometers were installed during construction. A tracked excavator dug a 1 m pit and trenched a narrow path to the stockpile edge. Probes were installed in the pit face and wires strung in the trench. The 1 m pit and trench were backfilled. Haul trucks were instructed to not drive on probes during soil placement. Sensors were connected to an automated data acquisition system a few weeks after stockpile construction. The system consisted of a CS CR10X datalogger and a CS AM16/32 multiplexer powered by a rechargeable battery and solar panel. The datalogger, multiplexer and batteries were housed in environmentally sealed fiberglass enclosures.

Calibration curves were determined in the laboratory for all replicates of each stockpile by O'kane Consultants Ltd. from bulk samples collected in two 20 L pails. Coefficients for volumetric water were C_0 = -3.3409, C_1 = 0.39368, C_2 = -0.01456, C_3 = 0.0001899 for Aurora stockpiles; C_0 = -1.366, C_1 = 0.1494, C_2 = -0.004759, C_3 = 0.0000565 for Albian; and C_0 = -2.566, C_1 = 0.3228, C_2 = -0.01313, C_3 = 0.0001875 for Canadian Natural Resources. Calibration equations for volumetric water content are as follows where x = sensor output, vwc = uncorrected volumetric water content, temp = soil temperature ºC and VWC = calibrated volumetric water content corrected for soil temperature.

$vwc = x-(20-temp)(0.526 - 0.052x +0.00136x^2)$, if $x \leq<27$

$vwc = x-(20-temp)(0.009x-0.013)$, if $x \geq 27$

$VWC = C_0+C_1vwc^2+C_3vwc^3$

Soil temperature and TDR measurements were made every two hours starting January 2007 until February 2009. Soil temperature and TDR measurements did not begin in Albian stockpiles until February 2007 when instrumentation was complete and TDR measurments in the small Albian stockpile ended in September 2008 due to complications with the data logger. Soil water content data are only presented between March 2007 and January 2008 in the CNRL large stockpile and soil temperature between February 2007 to February 2008; wires had been damaged during the last seed extraction period, therefore further monitoring did not occur. Soil water content data are only presented between February Monthly average soil temperature and volumetric water content graphs were developed by averaging mean daily temperatures and volumetric water contents for each month. Data is only presented

5.2.4 Soil Atmosphere

Soil atmosphere was assessed using permanent gas probes and analyzed by gas chromatography. Gas probes installed in May 2007 consisted of nalgene teflon tubing (0.635 cm inside diameter, 0.953 outside diameter) attached to the outside of a 2.54 cm sealed schedule 40 polyvinyl chloride pipe for support with an

Elite® air diffuser (Art # A-984 from Petsmart) connected to the bottom of the tubing and a Cole Palmer four way stop cock attached to the top. The air diffuser and stop cock were secured to the tubing with 19 gauge stainless steel wire. Gas probe lengths varied depending on installation depth. Another 100 cm of polyvinyl chloride pipe and 50 cm of nalgene teflon were used for each gas probe to assist in gas collection; therefore, a 6 m permanent gas probe would consist of a 7 m sealed polyvinyl chloride pipe with a 6.5 m nalgene teflon tube attached on the outside of the pipe. Gas probes were installed at 0.3, 1, 2, 3 and 4 m in large stockpiles and at 0.3, 1, 2 and 3 m in small stockpiles in a 5 cm diameter hole augered by hand. For each hole one gas probe was inserted 15 cm above the bottom and coarse sand was poured into the hole until 15 cm of sand was placed on the top of the probe. The hole was filled with 15 cm of bentonite chips and 1 L of water was poured down the hole to help bentonite seal the hole. The remaining portion of the hole was filled with stockpiled soil. A total of 108 permanent gas probes were installed, 5 per large stockpile and 4 per smallstockpile.

Soil gas was extracted from each gas probe from July 2007 until February 2008 at various time periods as determined by examining the data collected. Prior to taking a sample at each event the volume of gas in each tube was purged with a 60 ml polyethylene syringe. Sampling involved inserting the end of a 60 ml polyethylene syringe into one end of a four way stop cock with a sterile needle at the other end; the needle was inserted into the rubber septum of a 10 ml vacutainer and 14 ml of gas extracted and pumped into the vacutainer. Syringes were flushed with air between samples to prevent cross contamination. Two randomly selected vacutainer vials were used as blanks for each large and small stockpile replicate. Vacutainers were stored at 4 ºC in the dark until analysis.

Gas chromatography for carbon dioxide, oxygen, nitrogen and methane was determined on a Hewlett Packard 5890 gas chromatograph with a thermal conductivity detector, thermal conductivity conductor filament temperature was 120 ºC. Ethylene and samples containing low concentrations of methane were carried out on a Hewlett Packard gas chromatograph with a flame ionization detector, thermal conductivity conductor filament temperature was 80 ºC. Both

gas chromatographs were fitted with a CTR-1 column packed by Alltech and oven temperature was maintained at 35 ºC; the carrier gas was dry high purity oxygen scrubbed helium at a flow rate of 50 ml min^{-1}. Columns were calibrated using a standard 100 ppm of ethylene in argon for the flame ionization detector and thermal conductivity conductor. Vacutainers were brought to room temperature before analysis. Fifty µl samples were injected into the column attached to the flame ionization detector with a gas tight syringe and 250 µl samples were injected into the column attached to the thermal conductivity conductor. Samples containing high carbon dioxide analyzed with the thermal conductivity conductor were rerun and injected with 100 or 200 µl samples. Analysis time was 10 min per sample with the thermal conductivity conductor and 15 min per sample with the flame ionization detector. Fourteen blank samples were filled with 14 ml of carbon dioxide to determine methane, acetylene, oxygen and carbon dioxide contained in randomly selected vacutainers; the corrected concentrations of each gas of interest was determined by subtracting amount of gases in vacutainers by concentrations of analyzed gases in stockpiles. Analogue output from the gas chromatograph was captured and integrated using Shimadzu Class-VP chromatogram analysis software.

5.2.5 Seed Viability and Germination

Seeds were extracted from stockpiles in June 2007 and February 2008 using a tracked excavator which opened one end of the stockpile, opposite the instrumentation, from the top of the stockpile downward. To minimize missing a sachet, the excavator dug until cable and snow fence were exposed, then slowly dug to the sachet, which was removed with a hand shovel. During the second seed extraction in the large Aurora mine stockpiles, sachets could not be recovered from 6 m; viability and germination were averaged from three replicates. Seed bags were dried at room temperature with fanning for two weeks.

Viability was determined using tetrazolium on seeds before stockpiling, seeds extracted from the stockpile and on stored seeds. Four replicates of 25 seeds from

each species were tested. Half of the seeds from each seed bag were used for viability testing. A 1 % tetrazolium solution was prepared and used for all species. Tetrazolium solutions, seed treatments, cutting methods and staining evaluations were according to the Association of Official Seed Analysts (Peters 2000) and the International Seed Testing Association (2003). *Aralia nudicaulis* was the only species not in the above protocols so seeds were placed between damp paper towel overnight, then cut longitudinally in half, through the endosperm with a scalpel and stained with tetrazolium solution at 30 ºC in a dark oven for 18 h. Viable *Aralia nudicaulis* seeds had bright red stained embryos and endosperm. Seeds that had germinated or rotted at the time of retrieval were classified as non-viable because they did not exhibit the potential to germinate if stockpiled material was spread on reclamation areas.

Germination and emergence were determined in a controlled growth chamber for 8 weeks on seeds and roots before stockpiling, seeds and roots extracted from stockpiles and stored seeds. Stored roots were not used because all roots in storage at 4 ºC had initiated adventitious roots or shoots. For pre stockpile and stored conditions 25 seeds and 5 root cuttings with 4 replicates each were used. The remaining 25 seeds from seed bags and all roots were analyzed.

Seeds were placed on damp Anchor steel blue seed germination blotter paper in sealable, clear, 10 x 10 cm plastic germination containers. Roots were planted 1 cm deep in 50 x 30 cm plastic containers with holes in the bottom and filled with 5 cm of Terra-Lite® metromix. Seeds and roots were kept from drying by watering twice a week. Temperature and light conditions were 28 °C in the light for 16 h and 15 °C in the dark for 9 h. All containers were randomly switched to different locations weekly. Germination and root emergence was determined weekly. A seed was considered germinated when the first radical emerged and a root was considered emerged when the first shoot emerged.

Propagule emergence from samples was quantified using the emergence method in a growth chamber under controlled light and temperature conditions. Soil propagule bank samples were spread to a thickness of 3.7 cm in 10 x 12 cm

plastic containers lined with 1 cm of Terra-Lite® metromix. From each depth interval 50 samples were randomly placed in the growth chamber. Soils were watered as needed to prevent drying. Growth chamber temperatures and lighting were similar to conditions for seed germination. Emerged plants were identified and counted 2 weeks after potting and monthly thereafter for 6 months. Samples were remixed at 2 and 4 months to promote emergence by bringing up buried seeds and reducing thickness of the moss layer to promote light penetration (Thompson et al. 1997). Some species were not identifiable because of death between enumeration periods or prior to identifiable structures emerging.

5.2.6 Stockpile Soil Chemistry

Prior to salvaging, the top 15 cm of topsoil was sampled with a shovel. Sample and assessment locations were taken in a systematic grid, each location representing 4,000 m^2. Samples were placed in coolers and stored at 4 ºC until laboratory analysis to provide baseline conditions for the stockpile material.

Samples of stockpiled soil were collected during each seed extraction at each depth seed bags were extracted. At each depth the face of the stockpile was sampled with a 7.5 cm diameter core, 7.5 cm in length. Four discrete cores were pounded into the soil with a mallet and composited into one polyethylene bag for analysis. Bulk density samples were difficult to obtain due to roots and very compressed soil. Samples were thoroughly mixed by hand prior to submission to a commercial laboratory.

Most samples were analyzed according to Carter (1993). Saturation %, pH, electrical conductivity, sodium adsorption ratio, soluble cations (calcium, potassium, magnesium, sodium) and soluble anions (chloride, sulfate) were determined from saturated paste extract, total nitrogen by digestion with Devarda's alloy to convert nitrate to ammonium and total carbon by combustion. Extractable cations (calcium, potassium, magnesium, sodium) and cation exchange capacity were determined with ammonium acetate at pH 7.0. Available phosphorus and potassium were determined by modified kelowna extraction,

available ammonium and nitrate by extraction with 2.0 M potassium chloride, available micronutrients (copper, iron, zinc, manganese) with diethylene triamine pentacetic acid, available and extractable boron by hot water extraction and available sulphate by monocalcium phosphate extraction (Combs et al. 1998). Particle size was determined by hydrometer.

5.2.7 Statistical Analyses

Separate one way fixed effects analysis of variance (ANOVA) for each stockpile size and extraction/sampling period (8 months and 16 months) was used to determine if stockpiling affected seed viability, seed germination, root emergence and soil chemical properties by comparing response variables measured before and after stockpiling (Zar 1999). Significant main effects using one way ANOVA were analyzed using least squares difference (LSD) post hoc test for significant differences between response variables before and after stockpiling (Carmer and Swanson 1973). Two way fixed effects ANOVA for each extraction/sampling period was used to determine effects of stockpile size and burial depth on seed germination, seed viability and soil chemical properties, excluding response variables measured before stockpiling (Zar 1999). Significant interaction effects in two way ANOVA were analysed using one way ANOVAs to determine significant differences between depths for each stockpile size; if main effects were significant differences were further analyzed using LSD. Residuals from raw data were tested for normality using the Shapiro-Wilk test and heterogeneity of variances with Levene's test. Data were rank transformed when variances of raw data were heterogeneous. Means and standard errors were used to describe patterns for parameters not meeting assumptions for homogeneous variances. Analyses were conducted using SPSS 18.0; significance was at $p = <0.05$.

Spearman's rank correlation coefficient was used to compare strength of viability relationships of each species to select soil gases (carbon dioxide, methane, ethelyne, oxygen) and chemical properties (ammonium, iron, manganese) known to affect seed germination (Baskin and Baskin 1998) with SPSS 18.0. Separate

correlation analyses were done for large and small stockpiles. Thirty two samples were incorporated in the analysis of large stockpiles and 32 samples for small stockpiles. Data collected from the 6 m depth of large stockpiles were excluded from the analysis because no soil gas data were collected at that depth.

5.3 RESULTS AND DISCUSSION

5.3.1 Stockpiling Effects on Soil Attributes

Compared to undisturbed topsoil, stockpiling significantly changed many soil properties (Tables 5.1 to 5.6). Stockpiling increased temperature (Figures 5.1 and 5.2), volumetric water content (Figures 5.3 and 5.4) and soil atmospheres of carbon dioxide, methane and ethylene (Figures 5.6 and 5.7) with depth. Oxygen decreased with depth over time. Extractable boron and nitrate decreased with increased storage time. Available ammonium and phosphate, soluble potassium, electrical conductivity and sodium adsorption ratio substantially increased in large stockpiles, but not in small stockpiles..

Substantial changes to soil atmosphere and chemistry from stockpiling topsoil has been found in other research (Abdul-Kareem 1984, Kundu and Ghose 1997). In our study extreme anaerobic conditions occurred in large stockpiles shortly after construction and persisted; over time anaerobic conditions also occurred at depth in small stockpiles. These changes result from soil going from aerobic to anaerobic. The fine textured, large stockpile was most anaerobic. Anaerobic processes occur in soils when molecular oxygen is absent or in low concentrations (McDaniel 2006). Data extrapolated from McDaniel (2006) suggest anaerobic processes begin when redox potentials are 100 to 300 mV or soil oxygen is 4 to 8 %. Complete anaerobic conditions occur when soil redox potentials are < 100 mV or soil oxygen is < 4 %. Anaerobic conditions promote reduction of important elements in soils that are used as alternative electron acceptors, including nitrate, manganese dioxide, hydrated iron oxide, sulphate, carbon dioxide and water. Their reduction in anaerobic environments increase ammonium, manganese, iron,

hydrogen sulphide and methane. Nitrate, manganese dioxide and hydrated iron oxdide reduction can occur in hypoxic conditions where carbon dioxide and sulphate reduction occur under extreme anaerobic conditions (Tiedje et al. 1984).

The change from aerobic to anaerobic state in stockpiles can occur shortly after stockpiling or be a more subtle transition. Rate and magnitude of change is affected by porosity, organic matter content, water content and temperature, which regulate aerobic and anaerobic microbial activity. With the exception of organic matter content, stockpile size, construction time, soil depth and length of storage greatly influence these factors.

Changes to air filled porosity would cause the most abrupt change to the aerobic state of stockpiled soil, such as in our large stockpiles. The magnitude of change is significantly greater with increasing depths below 1 m. Increased equipment traffic and large amounts of piled soil result in compacted soil reducing aeration and air filled porosity. Although, bulk density could logistically not be measured, stockpiled topsoil has greater bulk density at increasing depths (McQueen and Ross 1982). With limited oxygen, aerobic respiration quickly switches to anaerobic, fuelled by organic matter in stockpiled soil. How fast the change occurs depends on temperature in the stockpiles. Stockpiles that initially became most anaerobic were constructed in fall or when soil temperatures was above 0 ºC below 1 m; the stockpile with the most total carbon (Canadian Natural Resources) was most anaerobic. Anaerobic respiration is enhanced with increasing soil water and soil temperature (Maag and Vinther 1999).

Small stockpiles became anaerobic over time, but not as anaerobic as large stockpiles, concentrations of methane (Figure 5.7) and ammonium and manganese (Tables 5.1 to 5.4) were lower in small stockpiles. When air temperatures dropped below 0 ºC, oxygen increased. Small stockpiles were much less compact than large stockpiles as indicated by less restistence when pounding in soil cores taking samples; this is an indication of lower bulk density, thus greater air filled porosity. The additional porosity would have allowed more oxygen within the stockpile to support aerobic respiration for a longer time. Increased aerobic respiration in

spring and early summer would have decreased oxygen, leading to anaerobic respiration. In June, the surface, 0.6 and 1.0 m depths were 10 ºC warmer than air temperature and by August all depths were 10 to 20 ºC warmer than air temperature. Increased soil temperature with depth was likely due to increased microbial activity. Piling topsoil with an abundant source of organic carbon is similar to creating a compost pile. Factors such as temperature and water content influence anaerobicity and while the winter constructed stockpile was initially less anaerobic than the fall constructed one, when snow melted, increased water caused the winter constructed stockpile to become much more anaerobic.

Substantial changes in soil chemistry in large stockpiles could have serious consequences for land reclamation. Ammonium can be lost by leaching, volatilization or run off once material is spread. Harris et al. (1993) show stockpiling topsoil increased lability of organic nitrogen making it more susceptible to mineralization, increasing potential for loss. Electrical conductivities in our stockpiles are low; however, continued increases could become intolerable for some native plants (Howat 2000). Increased major cations deep in the stockpiles likely result from leaching and desorption from exchange sties. Leaching of ions is considered negligible as highly mobile anions such as chloride did not increase much with depth. High concentrations of ammonium in soil likely displaced potassium on exchange sites, increasing soluble potassium (Havlin et al. 1999). High concentrations of carbon dioxide in the soil atmosphere increase hydrogen ions when carbon dioxide is dissolved in water and hydrogen ions displace calcium from exchange sites making it more soluble (Havlin et al. 1999). Increased soluble calcium and magnesium could have formed strong complexes with zinc, reducing its concentration. Increased availability of these nutrients along with increased concentrations of more mobile forms of manganese and iron make them more susceptible to leaching from the stockpile and after spreading on a reclamation landscape. Long term impacts to nutrient availability using spread stockpiled soil is unknown; a large pool of nutrients will likely be available shortly after soil placement and if nutrients are not taken up by plants, most could be lost to leaching, run off and volatilization.

5.3.2 Stockpiling Effects on Seed Viability and Germination

Stockpiling boreal forest topsoil rapidly reduced seed viability and germination and root emergence for most species tested, with continued reductions over time (Tables 5.8 to 5.25). Stockpiling resulted in a significant decline (up to 100 %) in seed viability of 24 of the 27 species in small and large stockpiles at most burial depths after 8 and 16 months. There were few significant differences with stockpile size and burial depth; however, after 8 months there were greater declines in viability below 1 m in large stockpiles. After 8 months root emergence declined more than 80 % for *Arctostaphylos uva-ursi*, *Maianthemum canadense* and *Vaccinium myrtilloides*; after 16 months no roots survived (Tables 5.24 and 5.25). Fall construction resulted in greater seed viability declines than winter construction; declines were greater in the fine textured stockpile than coarse textured stockpiles for most species.

Seed viability and germination did not differ significantly between extraction times and burial depths for most species, although trends of decreasing viability over time with increasing depth were clear. Other studies found stockpiling reduced native seed viability over a short time (Dickie et al. 1988, Rockich et al. 2000, Rivera et al. 2012). Rivera et al. (2012) found storage of topsoil in Spain significantly decreased seed viability and germination of 10 grass species within 6 months and with increased burial depth. Rockich et al. (2000) found no significant difference between storage time or burial depth on viability and germination of several *Banksia* species in Australia; most seed viability was lost after 1 month at all burial depths in the 3 m topsoil stockpile. Hall et al. (2009) found no significant effects of stockpiling topsoil from surface mines in Appalachia for 4 grass species over 8 months; however, seeds were only buried at 30 cm depth .

Ours is the only experiment that studied effects of stockpile size and burial depths > 3 m on seed viability and germination while concurrently measuring soil physical and chemical changes. Seed loss from stockpiling have mostly been attributed to in situ germination, predation, physical and mechanical damage or seed decomposition (Dickie et al 1988, Rockich et al. 2000, Rivera et al. 2012)

No studies provided direct evidence of causes for loss of seed viability. Rockich et al. (2000) attributed seed viability loss of *Banksia* species in topsoil stockpiles to high temperature and water content. Riveria et al. (2012) attributed loss of seed viability to in situ germination. Dickie et al. (1988) suggested anaerobic conditions deep in stockpiles would be a factor in seed viability reduction. Our research showed seed viability declined in both aerobic and anaerobic conditions.

Until detailed studies determine how environmental factors in stockpiles regulate seed viability of boreal species at the cellular level, exact mechanisms for killing seeds remains uncertain. It appears likely rapid loss of seed viability in small stockpiles and the upper 1 m of large stockpiles is mainly due to in situ germination, seed decay or rotting. Seed viability was negatively correlated with oxygen, suggesting aerobic processes led to mechanisms reducing seed viability (Tables 5.26 to 5.28). The complexity of interactions among soil temperature, atmosphere and chemical environment makes it difficult to determine factors promoting in situ seed germination given the lack of knowledge on germination requirements for most species used in this research. The literature suggests increased soil temperature, carbon dioxide, methane and nitrate concentrations can enhance seed germination, but too great an increase can prevent germination (Baskin and Baskin 1998). Accelerated seed decay or rotting is attributed to enhanced microbial activity from stockpiling soil rich in organic carbon. Bacteria and fungi are considered a major cause of buried seed death, although few field studies addressed this hypothesis (Baskin and Baskin 1998). Seeds in warm, damp conditions lose viability sooner than those in cool, damp conditions (Roberts and Abdalla 1968). Lower soil temperatures in winter constructed stockpiles would thus result in less seed death.

In large stockpiles, below 1 m, seed viability is likely lost due to mechanisms causing accelerated seed aging at the cellular level, caused by mechanisms from anaerobic conditions. Seed viability of most species was positively correlated with oxygen and negatively correlated with available ammonium, iron and manganese and with methane and carbon dioxide (Tables 5.26 to 5.28). Major environmental factors recognized as deleterious for seed survival are temperature,

water content and oxygen (Harrison 1972, Ibrahim et al. 1983, Ohlrogge and Kernan et al. 1982). Seeds of agricultural species in environments with reduced oxygen often retain viability longer than if stored with ample oxygen (Roberts and Abdalla 1968). However, when seed water content is above a critical point (15 % for barley) anaerobic environments are deleterious to their survival (Ibrahim et al. 1983). Seeds extracted from great depths in our large stockpiles had no signs of radical emergence although they were imbided with water. Ibrahim et al (1983) found seeds of various agronomic species stored at water contents 15 % or higher had increased subcellular damage and under anaerobic conditions only survived for short periods because no oxygen was available for subcellular repair. It is not surprising, given environmental conditions in large stockpiles, that seed viability was positively correlated with oxygen. Other causes of reduced seed viability include viruses, bacteria or toxic concentrations of compounds such as ethanol.

5.3.3 Species Response to Stockpiling

Geranium bicknellii and *Dracocephalum parviflorum* resisted deleterious effects of stockpiling. Both are annual or biennial, early successional in boreal forest and seed banking (Archibald 1989, Fyles 1989). Their germination is promoted by heat from forest fires (Lee 2004). They were likely less affected by stockpiling because they have hard, impermeable seed coats (Conn 1990, Gama-Archchige et al. 2012). Dickie et al. (1988) found only one species, *Juncus bufonius*, had numerous viable seeds at greatest burial depths in topsoil stockpiles in Derbyshire. They did not mention mechanisms leading to greater survival. Rivera et al. (2012) found large seed mortality was negatively related to seed mass. Although we did not measure seed mass, small, light weight seed lost viability just as easily as large, heavy seeds.

Other species with a less dramatic decline in seed viability had harder seed coats than seeds of species that declined abruptly. Species with hard seed coats, (*Geranium bicknellii*, *Dracephalum parviflorum*, *Virburnum edule*, *Cornus Canadensis, Vicia Americana, Prunus pensylvanica*) generally maintained greater

viability over time at multiple burial depths than seeds without hard seed coats (*Bromus ciliatus*, *Fragaria virginiana*, *Ribes hudsonianum*, *Vaccinium myrtilloides*). Seeds of *Vicia americana* that were not fully ripe and became soft after a short soaking lost more viability then seeds that were fully ripe.

Seeds with a hard coat that allows water exchange, like *Prunus pensylvanica*, lost viability quickly. Seeds with physical dormancy would not be as affected initially by stockpiling, unless the seed coat was scarified and made permeable. Seeds with physical dormancy that are impermeable to water are able to remain inactive and sustain low respiration rates. Rockich et al (2000) and Brophy (1980) noted legume species with hard seed coats retained high viability in stockpiled topsoil.

Seeds that do not have physical dormancy are completely vulnerable to the surrounding deleterious environment. Species with low respiration rates or with persistent seed banks might tolerate greater burial depths in stockpiles; however, this was not the case for all species with persistent seed banks. *Rubus idaeus* and *Prunus pensylvancia* are shrubs with known seed banking capabilities and seeds can stay viable in the soil for 100 to 200 years (Marks 1974, Whitney 1986). Loss of up to 100 % viability at depths > 1 m in the stockpiles for these species is surprising considering their natural longevity in the soil. Once seed of most dry land species has imbibed water, respiratory activity and oxygen consumption increases (Bewley 1997). Without oxygen at great depths in large stockpiles, seeds cannot repair cellular damage from initial influx of water into cells. Seeds in environments that facilitate respiration will lose viability more rapidly than those that do not, unless those species have mechanisms to keep respiration rates low (wetland species tolerant to anoxic conditions) or prevent the surrounding environment from influencing seed integrity, such as physical dormancy seeds.

5.3.4 Stockpile Construction Methods

Direct placement of forest topsoil should be the preferred soil handling technique; however, stockpiling soil is a necessary component of reclamation and soils handling for any mine. There is little direction on how to construct stockpiles to

maintain seed viability, and to a lesser extent, reduce negative effects on soil quality. Our research has shown that regardless of stockpile size most species will lose seed viability within a relatively short period of time (< 8 months) at depths below the surface of the stockpile; however, there are less detrimental changes to soil chemistry in small stockpiles. This research suggests the best solution to maintain a native seed bank and minimize nutrient losses from stockpiled boreal forest topsoil for future use in revegetation would be to construct several small stockpiles rather than fewer large stockpiles. This would increase the overall surface area of stockpiled soil, reducing the volume of anaerobic soil conditions. Rivera et al. (2012) proposed construction of large stockpiles only for a short time to reduce seed loss in topsoil; however, our research suggests large stockpiles reduce seed viability more quickly than in small stockpiles.

Seed viability for a wide range of species could be maintained over the long term by building a new seed bank from newly established plants emerging from the former seed bank at the stockpile surface. However, space is often limited in the oil sands, preventing construction of several small stockpiles. Alternative placement locations such as former stockpiles constructed from reclamation materials other than upland topsoil is a potential solution to finding more available space.

Constructing stockpiles in winter or when soils are dry could reduce deleterious effects of stockpiling, at least in the short term. Anderson et al. (1988) found wet constructed stockpiles became more anaerobic than dry constructed ones. In the boreal forest waiting until conditions are dry is not practical. Low temperatures can be used advantageously for constructing stockpiles to maintain seed viability and reduce impacts to soil quality, even though benefits will be short lived unless stockpiles are constructed to prevent topsoil from thawing and becoming saturated with water from snow melt. Capping topsoil that has been salvaged and stockpiled during frozen months with a thick layer of peat could help minimize thaw rate.

The long term effects of storing soil in the boreal forest on quality and quantity of organic carbon and effects on chemical properties needs to be determined.

Research has shown stockpiling soil results in reduced aggregate stability making soils more prone to erosion and susceptible to compaction once replaced (Hunter and Currie 1956). Stockpiling topsoil causes significant alterations to microbial community composition and abundance (Harris et al. 1989). This research has demonstrated that various soil nutrients such as ammonium, potassium, calcium, manganese and iron become much more concentrated in their soluble forms after stockpiling. Specific revegetation methods and management may be required for reclaiming stockpiled topsoil to sustainable boreal forests due to the drastic changes of the soils chemical and physical state.

5.4 CONCLUSIONS

Stockpiling boreal forest topsoil is deleterious to seeds and changes many soil chemical and atmospheric parameters. The deleterious effect is greatest with large stockpiles, with fine textured soils and construction under non frozen conditions.

Boreal forest topsoil is rapidly altered with storage. With large and small stockpile size, seeds buried below 1 m rapidly lost viability. Anaerobic soil conditions occurred rapidly and persisted at depths below 1 m in large stockpiles; in small stockpiles anaerobic conditions occurred, then became aerobic when monthly air temperatures fell below 0 ºC.

In small stockpiles seed viability was lost because of processes occurring under aerobic conditions that enhanced in situ germination and seed decay. Lack of oxygen in combination with temperatures above 0 ºC and soil with enough water to imbide seeds caused the rapid loss in seed viability in large stockpiles. Only seeds of *Geranium bicknellii* and *Dracocephalum parviflorum* had a high survival rate in stockpiles; both species have hard seed coats and are physically dormant.

Direct placement of boreal forest topsoil is the preferred soil handling technique; however, when stockpiling is required construction of more, small stockpiles would help retain seed and propagule viability in the short term and a greater surface area with viable seed and propagule banks would be created long term.

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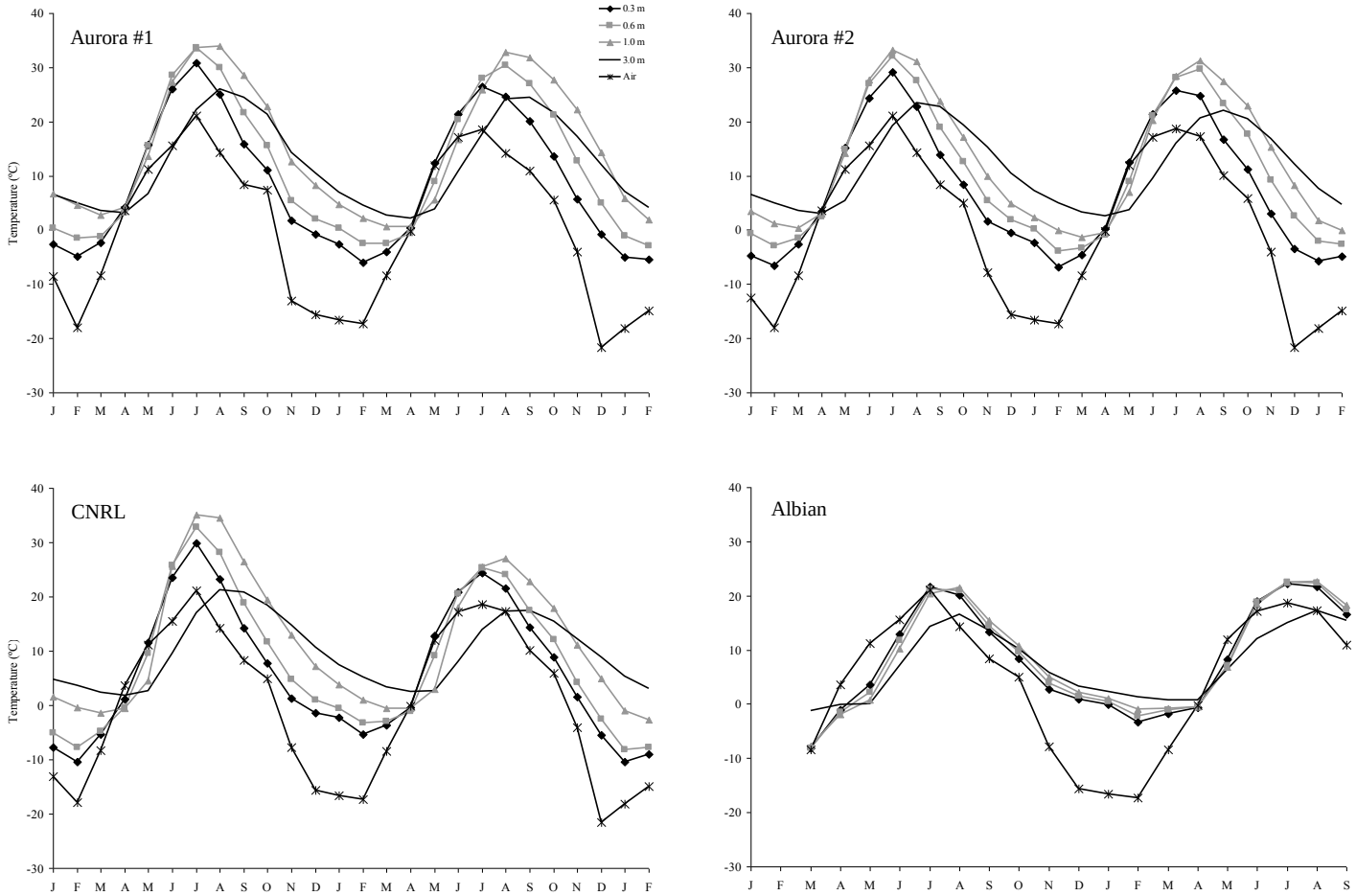

Figure 5.1. Monthly average soil temperature at depth for small stockpiles between January 2007 and February 2009.

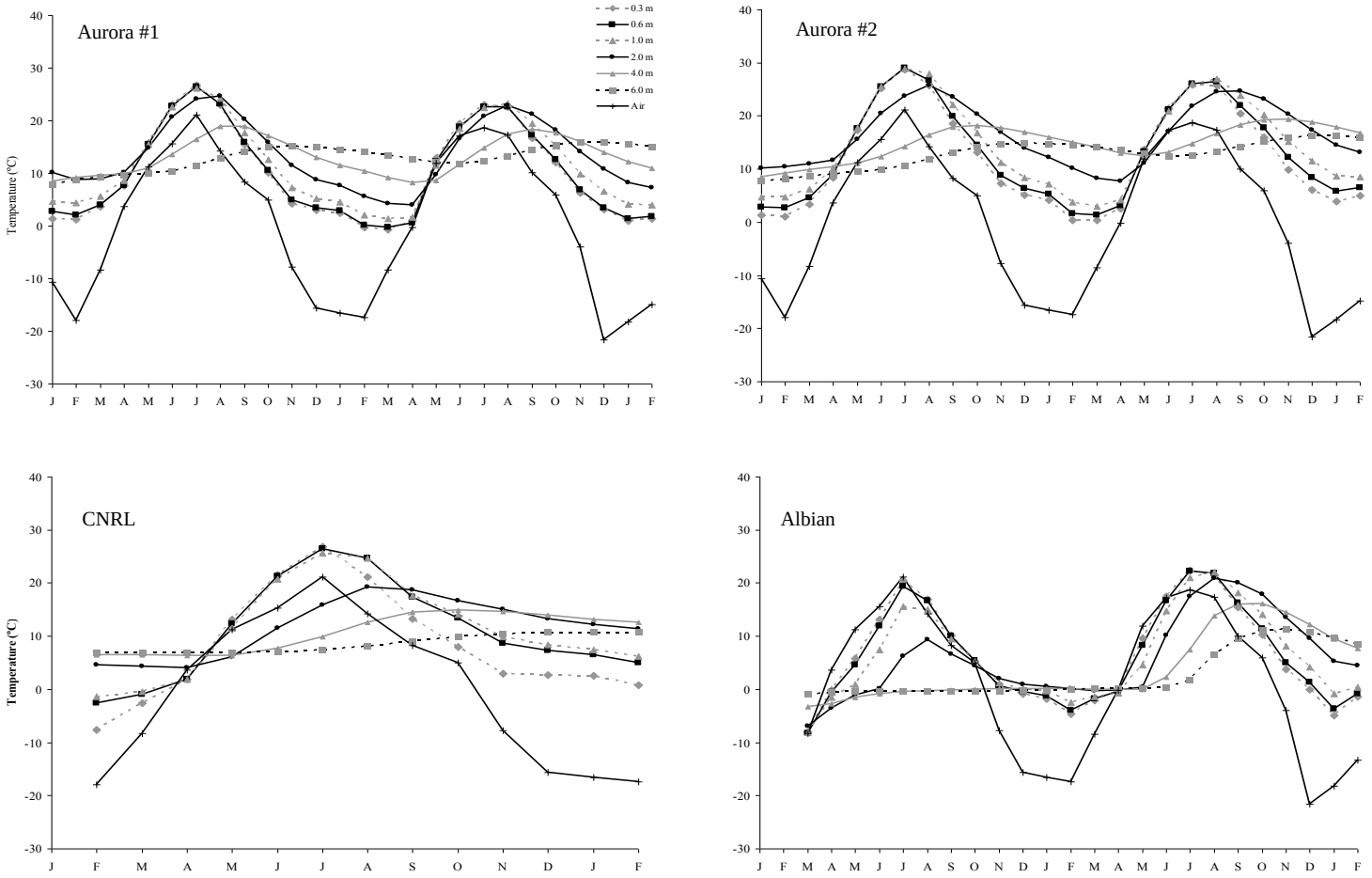

Figure 5.2. Monthly average soil temperature at depth for large stockpiles between January 2007 and February 2009.

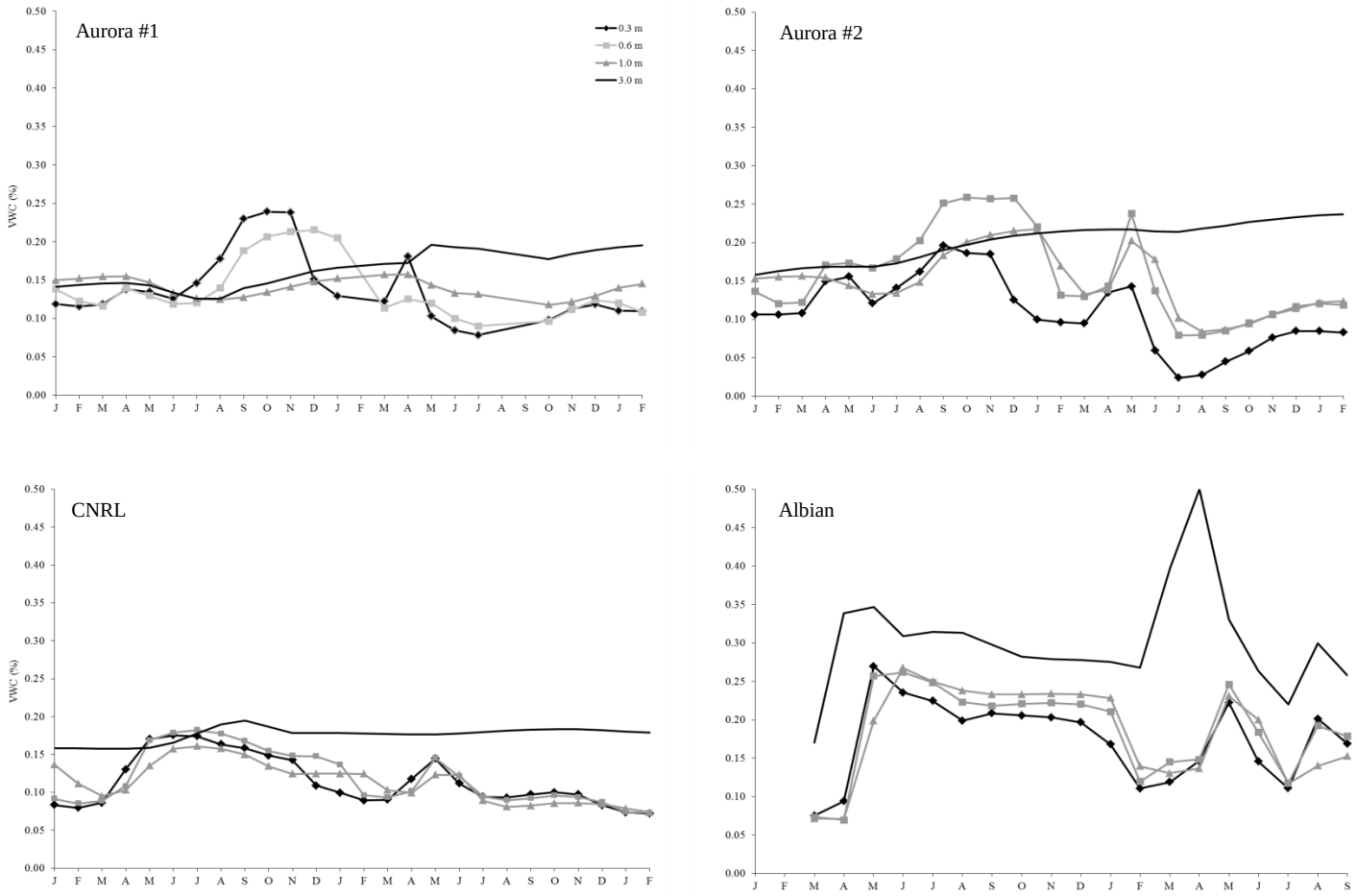

Figure 5.3. Monthly average volumetric water content (VMC) by depth in small stockpiles between January 2007 and February 2009.

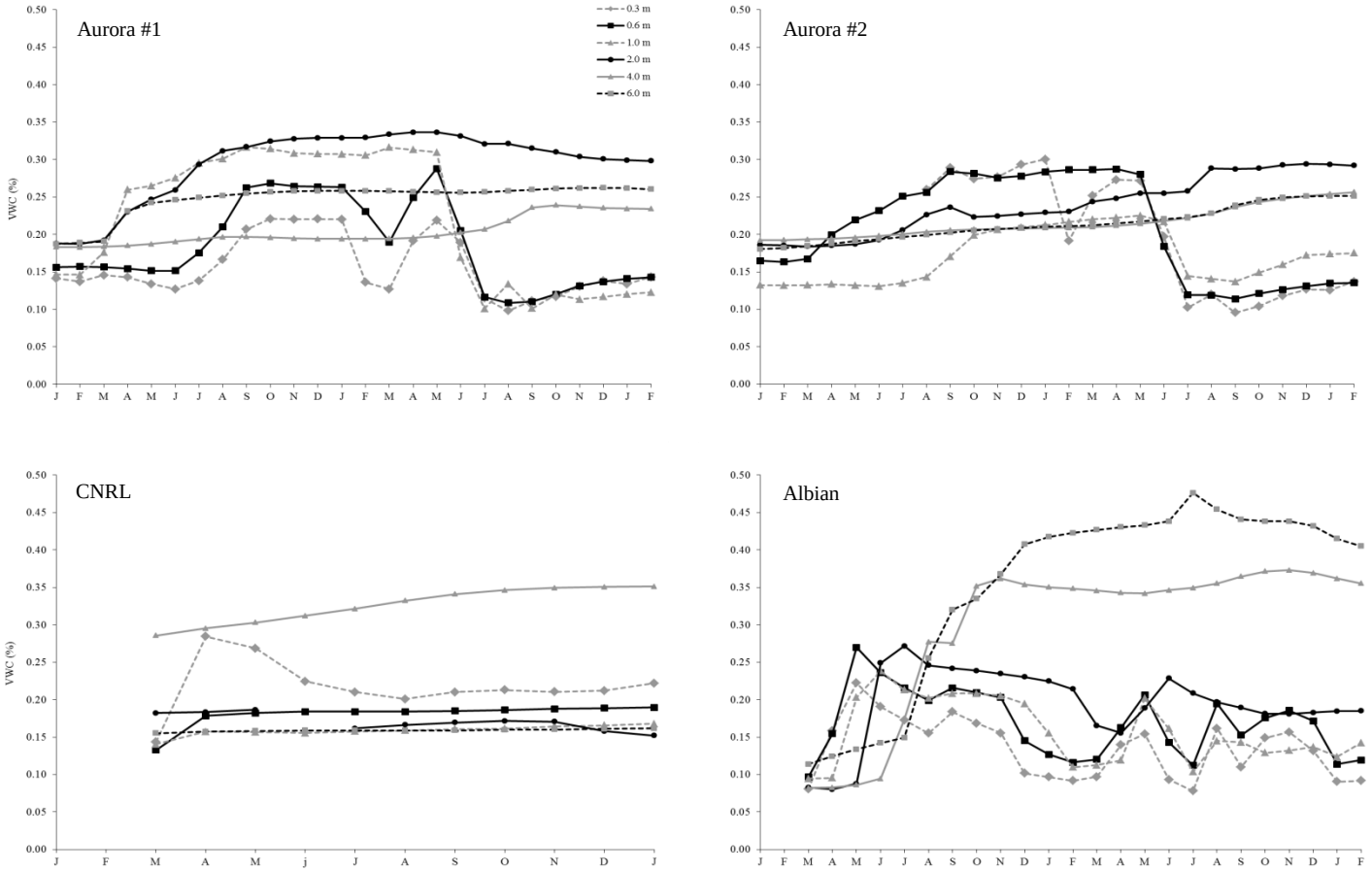

Figure 5.4. Monthly average volumetric water content (VWC) by depth in four large stockpiles between January 2007 and February 2009.

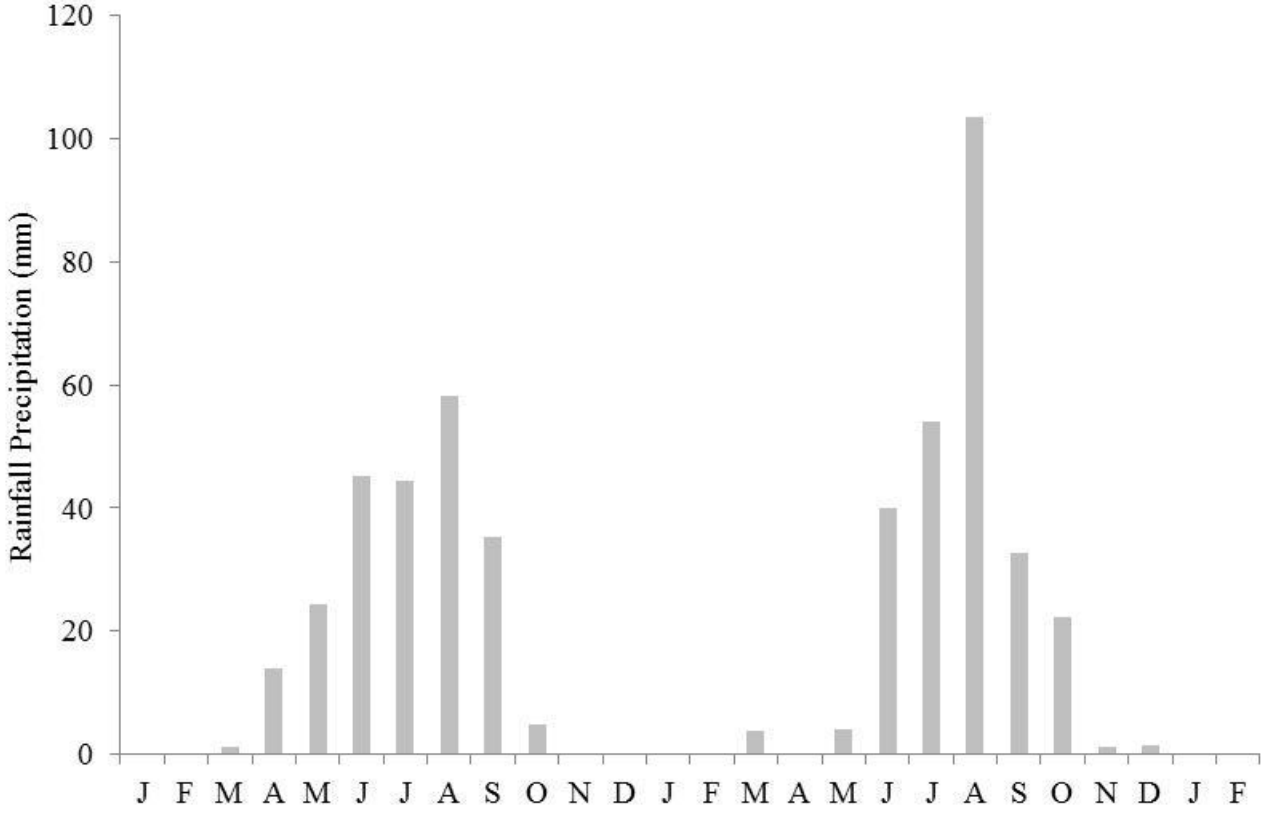

Figure 5.5. Monthly total precipitation as rainfall between January 2007 and February 2009.

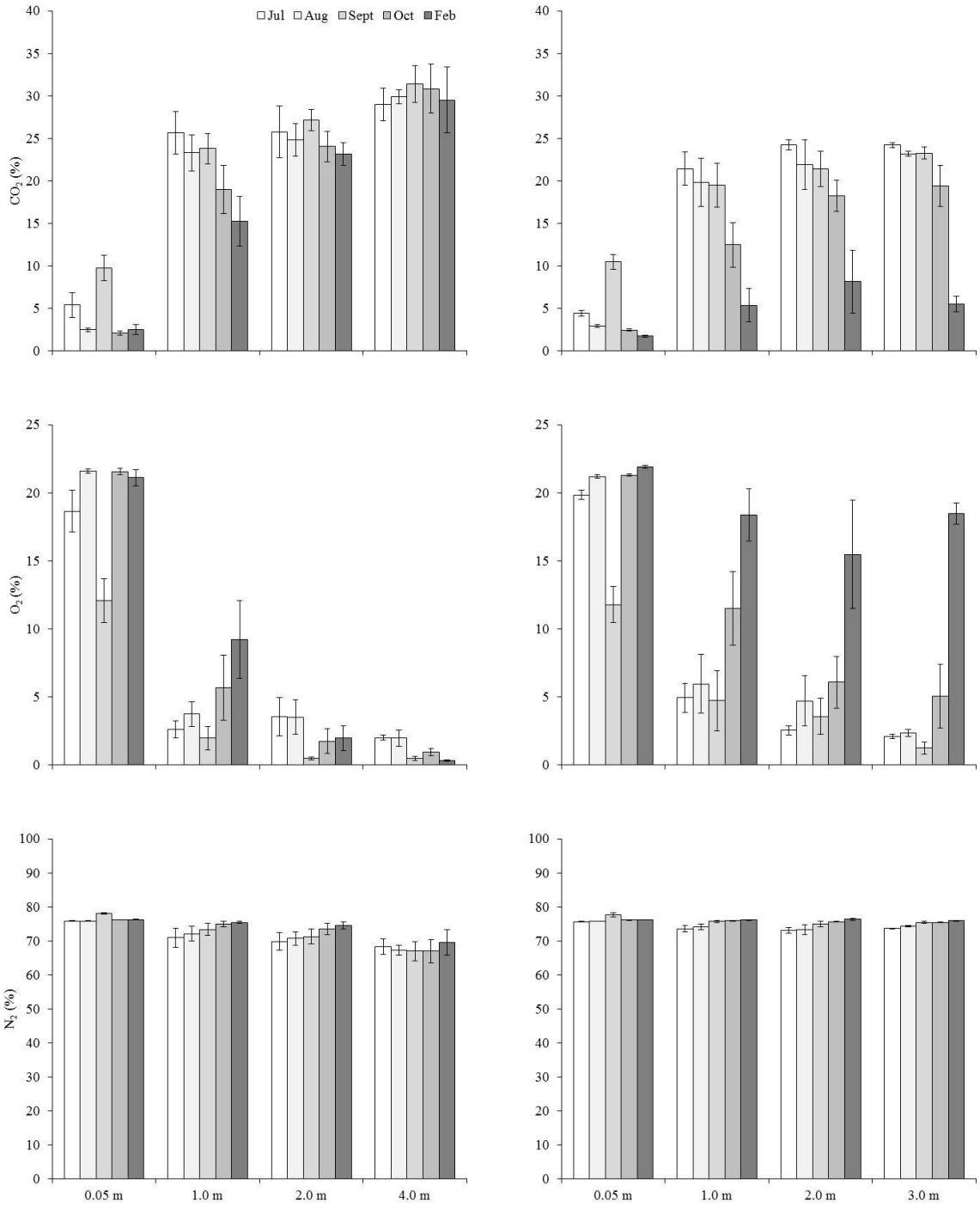

Figure 5.6. Monthly average soil atmosphere carbon dioxide, oxygen and nitrogen concentrations by depth for large (left) and small stockpiles (right). n=4.

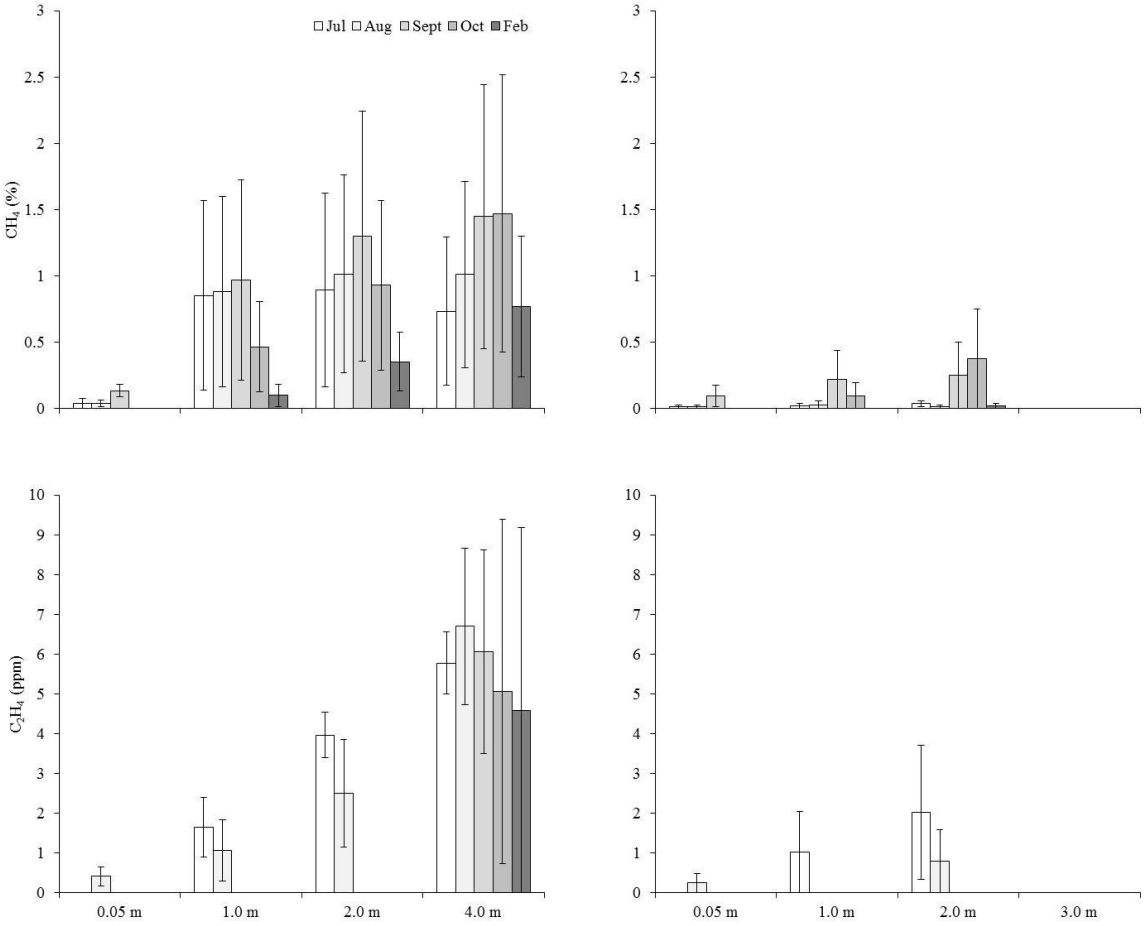

Figure 5.7. Monthly average soil atmosphere methane and ethylene concentrations by depth for large (left) and small stockpiles (right). n=4.

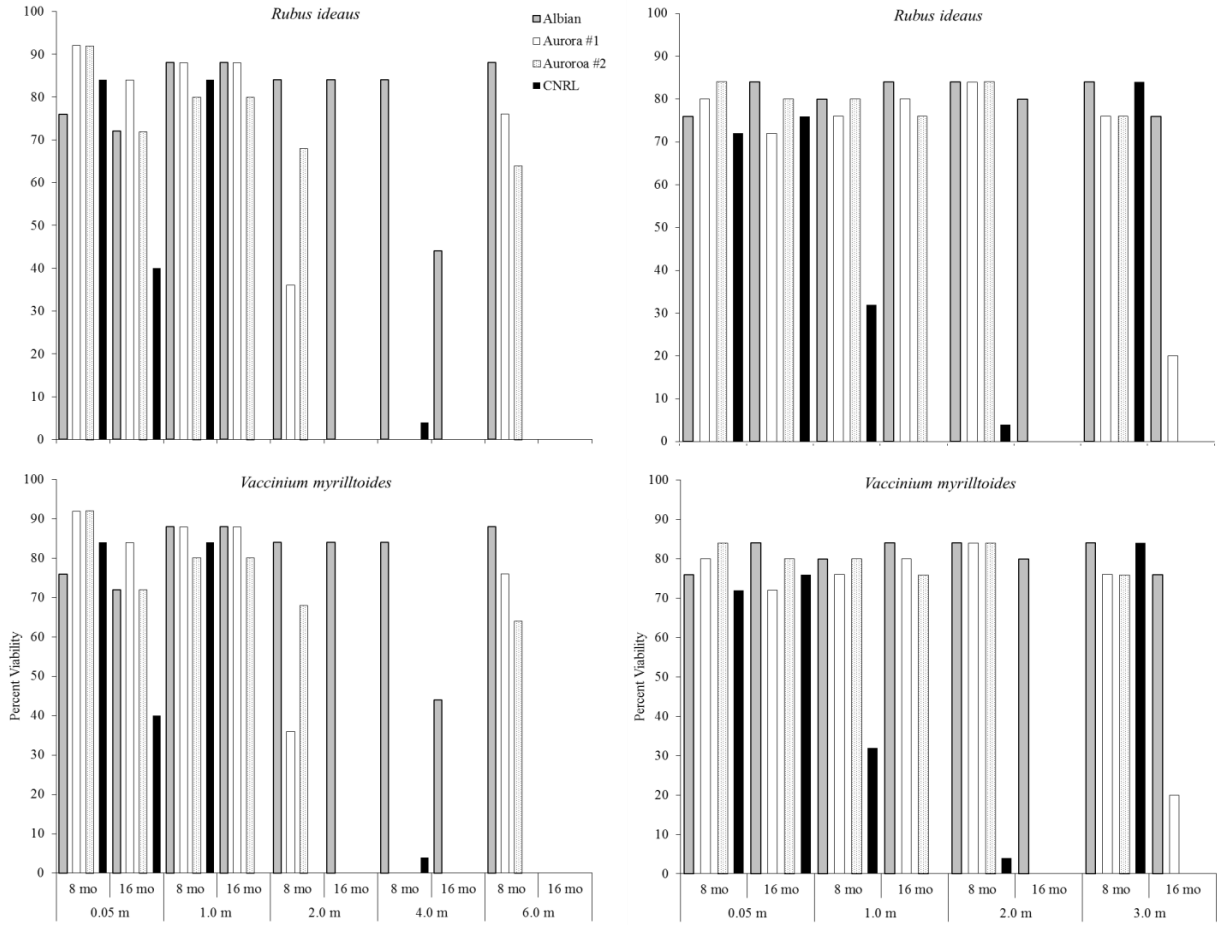

Figure 5.8. Seed viability of *Rubus idaeus* and *Vaccinium myrtilloides* after extraction from large (left) and small stockpiles (right).

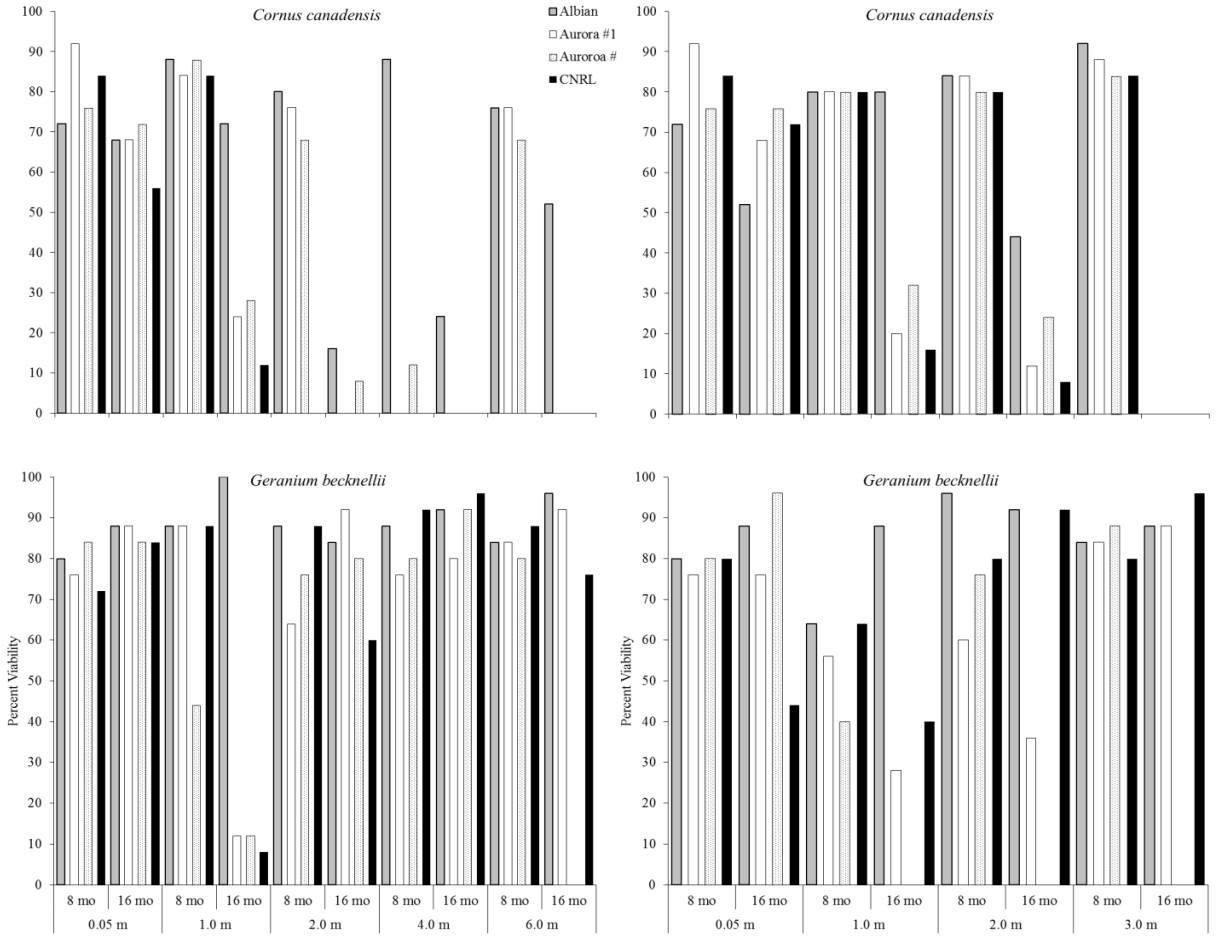

Figure 5.9. Seed viability of *Cornus canadensis* and *Geranium becknellii* after extraction from large (left) and small stockpiles (right).

Table 5.1. Mean soil properties and available macro nutrient concentrations for burial depths after 8 months of storage in large and small stockpiles.

Species	Control	Large Stockpile					Small Stockpile				p Values	
		0.05 m	1.0 m	2.0 m	4.0 m	6.0 m	0.05 m	1.0 m	2.0 m	3.0 m	One Way ANOVA	
											Large	Small
pH	5.6 (0.2)	5.7 (0.4)	6.0 (0.6)	6.0 (0.5)	6.0 (0.4)	5.7 (0.3)	5.3 (0.2)	5.4 (0.3)	5.4 (0.2)	5.4 (0.3)	0.987[2]	0.948
Electrical conductivity (dS/m)	0.4 (0.0)	0.4 (0.1)	0.4 (0.1)	0.7 (0.4)	0.8 (0.3)	0.9 (0.5)	0.3 (0.1)	0.3 (0.0)	0.3 (0.1)	0.3 (0.1)	0.857[2]	0.350
Sodium adsorption ratio	0.5 (0.0)	0.4[B] (0.0)	0.5[B] (0.1)	0.4[B] (0.0)	0.4[B] (0.1)	0.4[B] (0.1)	0.5[A] (0.1)	0.6[A] (0.0)	0.5[A] (0.0)	0.5[A] (0.0)	0.678	0.634
Total carbon (%)	2.1 (0.6)	1.8 (0.3)	1.8 (0.3)	1.8 (0.3)	2.1 (0.4)	2.0 (0.3)	1.6 (0.2)	1.7 (0.2)	1.6 (0.2)	1.4 (0.1)	0.987	0.651
Total nitrogen (%)	0.1 (0.0)	0.1 (0.0)	0.1 (0.0)	0.1 (0.0)	0.1 (0.0)	0.1 (0.0)	0.1 (0.0)	0.1 (0.0)	0.1 (0.0)	0.1 (0.0)	0.996	0.846
		Available Macro Nutrients (mg kg^{-1})										
Ammonium	3.1 (0.3)	2.0[A] (0.3)	8.3[A] (3.3)	10.2[*A] (2.4)	8.8[A] (2.1)	9.3[A] (3.5)	1.9[B] (0.5)	3.7[B] (2.2)	4.0[B] (1.8)	2.6[B] (0.7)	0.028[2]	0.507[2]
Nitrate	2.3 (0.2)	2.1 (0.3)	2.2 (0.3)	1.8 (0.1)	1.9 (0.3)	1.8 (0.1)	2.9 (1.3)	1.9 (0.3)	1.7 (0.1)	1.6 (0.1)	0.775[2]	0.474[2]
Phosphorous	17.9 (3.1)	16.5 (3.9)	16.5 (3.6)	19.0 (1.1)	26.5 (3.1)	23.8 (4.8)	13.5 (2.4)	16.5 (1.4)	17.3 (1.3)	18.5 (1.9)	0.249	0.524
Potassium	95.8 (19.9)	59.0 (13.6)	98.0 (22.3)	106.8 (35.4)	125.8 (51.0)	99.0 (29.3)	53.3 (14.0)	72.8 (18.6)	69.3 (21.3)	66.8 (12.3)	0.778	0.531[2]

Data are mean and (standard error), n=4. In rows * denotes LFH treatments significantly different from the control. In rows different letters denote significant differences, where upper case letters denote a significant difference between stockpile size and lower case letters denote a significant difference between burial depths. Significant difference at $p \leq 0.05$. [2] rank transformed for data analysis.

Table 5.2. Mean values for soluble ions, extractable boron and available micro nutrient concentrations for each burial depth after 8 months of storage in large and small stockpiles.

Species	Control	Large Stockpile					Small Stockpile				p Values	
		0.05 m	1.0 m	2.0 m	4.0 m	6.0 m	0.05 m	1.0 m	2.0 m	3.0 m	One Way ANOVA	
											Large	Small
						Soluble Ions (mg L^{-1})						
Calcium	46.8	55.0	45.5	107.8	124.5	164.3	37.8	31.0	35.5	39.3	0.888[2]	0.877
	(8.9)	(20.7)	(16.2)	(71.2)	(74.1)	(121.2)	(11.1)	(7.8)	(11.6)	(13.1)		
Chloride	32.7	21.5	25.0	28.0	31.0	32.3	21.5	26.5	27.0	26.3	0.647	0.641
	(5.1)	(2.7)	(5.3)	(3.3)	(8.5)	(5.6)	(1.0)	(5.5)	(7.0)	(3.9)		
Magnesium	12.0	15.8	11.0	28.5	32.8	44.8	10.3	8.5	9.5	10.5	0.917[2]	0.979
	(2.8)	(8.0)	(5.1)	(21.6)	(21.4)	(34.3)	(3.4)	(3.7)	(4.5)	(5.0)		
Potassium	19.7	13.0^{Ac}	23.0^{Ab}	31.8^{Ab}	42.3^{Aa}	36.0^{Aa}	9.5^{Bc}	13.0^{Bb}	11.8^{Bb}	13.0^{Bb}	0.064[2]	0.129
	(5.0)	(3.2)	(6.4)	(8.3)	(12.7)	(11.6)	(1.6)	(1.6)	(1.2)	(1.8)		
Sodium	13.4	12.3	13.3	14.0	12.0	12.3	13.8	13.8	12.5	13.3	0.996	0.996
	(1.5)	(2.4)	(4.5)	(4.4)	(2.1)	(1.7)	(2.6)	(2.8)	(2.5)	(3.0)		
Sulphate	46.2	66.2	46.6	29.2	29.0	37.8	49.0	45.0	43.1	32.8	0.326[2]	0.799[2]
	(5.4)	(26.5)	(10.2)	(1.2)	(6.1)	(3.9)	(13.8)	(12.7)	(11.8)	(4.9)		
						Extractable Boron (mg kg^{-1}) and Available Micro Nutrients (mg kg^{-1})						
Boron	0.4	0.5	0.5	0.6	0.6	0.5	0.4	0.5	0.5	0.5	0.994	0.991
	(0.2)	(0.2)	(0.2)	(0.2)	(0.2)	(0.2)	(0.1)	(0.2)	(0.2)	(0.1)		
Copper	0.3	0.3^{A}	0.3^{A}	0.3^{A}	0.3^{A}	0.3^{A}	0.2^{B}	0.2^{B}	0.2^{B}	0.2^{B}	0.965	0.147
	(0.1)	(0.1)	(0.1)	(0.0)	(0.1)	(0.1)	(0.0)	(0.0)	(0.0)	(0.0)		
Iron	51.7	47.5	64.0	63.3	74.3	61.5	57.0	63.3	68.3	67.5	0.466	0.253
	(6.2)	(8.4)	(10.5)	(14.8)	(7.6)	(8.5)	(2.7)	(6.8)	(7.1)	(5.0)		
Manganese	53.3	25.7^{Ac}	37.3^{Ac}	98.4^{*Ab}	136.5^{*Aa}	130.3^{*Aa}	24.7^{Bc}	18.2^{Bc}	29.7^{Bb}	63.5^{Bb}	<0.001	0.235
	(12.8)	(6.8)	(6.3)	(12.8)	(18.1)	(25.4)	(4.4)	(2.6)	(8.8)	(30.8)		
Zinc	2.8	1.6	1.6	1.7	2.3	2.0	1.3^{*}	1.9^{*}	2.8	1.8	0.354[2]	0.025[2]
	(0.2)	(0.2)	(0.2)	(0.3)	(0.6)	(0.6)	(0.2)	(0.4)	(1.2)	(0.3)		

Data are mean and (standard error), n=4. In rows * denotes LFH treatments significantly different from the control. In rows different letters denote significant differences, where upper case letters denote a significant difference between stockpile size and lower case letters denote a significant difference between burial depths. Significant difference at $p \leq 0.05$. [2] rank transformed for data analysis.

Table 5.3. Mean values for soil properties and available macro nutrient concentrations for burial depths after 16 months of storage in large and small stockpiles.

Species	Control	Large Stockpile					Small Stockpile				p Values	
		0.05 m	1.0 m	2.0 m	4.0 m	6.0 m	0.05 m	1.0 m	2.0 m	3.0 m	One Way ANOVA	
											Large	Small
pH	5.6	5.9	5.9	6.0	5.5	5.4	5.7	5.7	5.7	5.6	0.832	0.982
	(0.2)	(0.4)	(0.5)	(0.4)	(0.4)	(0.3)	(0.2)	(0.2)	(0.2)	(0.3)		
Electrical conductivity (dS/m)	0.4	0.7	0.5	0.7	1.5^{*}	1.6^{*}	0.6	0.4	0.4	0.3	0.019^{2}	0.504^{2}
	(0.0)	(0.1)	(0.0)	(0.3)	(0.5)	(0.5)	(0.1)	(0.0)	(0.0)	(0.0)		
Sodium adsorption ratio	0.5	0.4^{B}	0.5^{B}	0.5^{B}	0.3^{B}	0.2^{*B}	0.7^{A}	0.6^{A}	0.6^{A}	0.7^{A}	0.029	0.168
	(0.0)	(0.0)	(0.1)	(0.1)	(0.1)	(0.0)	(0.1)	(0.1)	(0.1)	(0.0)		
Total carbon (%)	2.1	2.2	2.0	1.9	2.3	2.0	2.0	1.7	1.6	1.4	0.964	0.600
	(0.6)	(0.3)	(0.2)	(0.3)	(0.2)	(0.4)	(0.3)	(0.2)	(0.1)	(0.3)		
Total nitrogen (%)	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.906	0.283
	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)		
					Available Nutrients (mg kg^{-1})							
Ammonium	3.1	5.7^{*c}	12.0^{*b}	15.0^{*ab}	20.0^{*a}	18.6^{*ab}	6.7^{c}	10.9^{*bc}	13.5^{*ab}	12.3^{*abc}	$<0.001^{2}$	0.013^{2}
	(0.3)	(0.6)	(3.4)	(3.7)	(3.2)	(4.7)	(2.2)	(3.0)	(4.1)	(2.3)		
Nitrate	2.3	5.1^{a}	6.20^{a}	1.0^{b}	0.6^{b}	0.6^{b}	1.3	3.7	1.7	0.9	$<0.001^{2}$	0.142^{2}
	(0.2)	(1.5)	(2.2)	(0.2)	(0.1)	(0.0)	(0.5)	(2.2)	(0.8)	(0.3)		
Phosphorous	17.9	18.5	19.8	20.3	25.5	31.5	22.0	21.3	26.3	18.0	0.219	0.715
	(3.1)	(3.9)	(3.7)	(4.6)	(4.7)	(5.0)	(3.9)	(4.0)	(4.4)	(7.2)		
Potassium	95.8	101.0	89.3	96.8	101.8	107.0	137.8	82.8	101.0	67.8	0.997	0.575^{2}
	(19.9)	(29.4)	(13.2)	(20.8)	(30.9)	(31.1)	(54.8)	(15.9)	(20.1)	(12.8)		
Sulphate	8.7	11.0	5.0	2.8^{*}	5.0	6.3	9.0	6.3	4.3	3.5	0.025^{2}	0.089
	(1.2)	(4.1)	(0.4)	(0.9)	(0.4)	(0.9)	(2.9)	(1.7)	(0.3)	(0.5)		

Data are mean and (standard error), n=4. In rows * denotes LFH treatments significantly different from the control. In rows different letters denote significant differences, where upper case letters denote a significant difference between stockpile size and lower case letters denote a significant difference between burial depths. Significant difference at $p \leq 0.05$. [2] rank transformed for data analysis.

Table 5.4. Mean values for soluble ions, extractable boron and available micro nutrient concentrations for burial depths after 16 months of storage in large and small stockpiles.

Species	Control	Large Stockpile					Small Stockpile				p Values	
		0.05 m	1.0 m	2.0 m	4.0 m	6.0 m	0.05 m	1.0 m	2.0 m	3.0 m	One Way ANOVA	
											Large	Small
						Soluble Ions (mg L^{-1})						
Calcium	46.8	89.5^{bc}	66.5^{c}	93.0^{c}	275.3^{*ab}	295.3^{*a}	60.8^{cd}	40.0^{c}	44.3^{c}	31.3^{d}	0.027[2]	0.412
	(8.9)	(17.5)	(17.1)	(51.0)	(153.3)	(145.8)	(15.6)	(9.2)	(10.4)	(6.0)		
Chloride	32.7	25.5	27.5	25.0	30.5	29.5	69.5	24.8	40.8	30.0	0.619	0.228[2]
	(5.1)	(7.6)	(4.9)	(4.2)	(4.7)	(6.8)	(34.7)	(1.1)	(9.6)	(7.5)		
Magnesium	12.0	24.8	16.5	27.8	74.8	76.3	16.0	11.5	12.3	8.8	0.063[2]	0.654
	(2.8)	(4.9)	(4.8)	(17.6)	(45.6)	(41.3)	(3.3)	(3.2)	(4.4)	(2.3)		
Potassium	19.7	32.3	25.3	29.8	51.3*	60.5*	51.0	16.8	18.3	12.3	0.031	0.718[1]
	(5.0)	(14.2)	(6.4)	(3.6)	(6.0)	(12.6)	(38.3)	(4.3)	(1.7)	(3.1)		
Sodium	13.4	16.5	16.8	15.5	16.5	14.3	20.0	15.5	17.5	17.3	0.948	0.339
	(1.5)	(3.0)	(2.0)	(3.3)	(4.6)	(2.1)	(3.1)	(0.6)	(2.1)	(2.9)		
Sulphate	46.2	122.7	50.6	32.0	46.3	47.9	80.8	57.8	51.8	47.6	0.187[2]	0.449[2]
	(5.4)	(41.1)	(5.7)	(5.9)	(5.8)	(2.8)	(18.2)	(8.4)	(2.2)	(4.1)		
						Extractable Boron (mg kg^{-1}) and Available Micro Nutrients (mg kg^{-1})						
Boron	0.4	0.4	0.3	0.3	0.3	0.3	0.5	0.4	0.4	0.2	0.980	0.858
	(0.2)	(0.2)	(0.2)	(0.1)	(0.2)	(0.1)	(0.2)	(0.2)	(0.2)	(0.1)		
Copper	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.791	0.984
	(0.1)	(0.0)	(0.0)	(0.1)	(0.1)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)		
Iron	51.7	47.3	79.0	146.0	99.3	82.0	62.3	58.3	74.5	83.5	0.058[2]	0.290[2]
	(6.2)	(13.1)	(17.0)	(61.8)	(11.7)	(14.1)	(12.2)	(12.6)	(3.8)	(7.9)		
Manganese	53.3	17.5^{*b}	46.6^{b}	178.3^{*a}	225.0^{*a}	266.0^{*a}	50.6	20.9	52.3	55.9	<0.001[2]	0.755
	(12.8)	(5.0)	(18.0)	(24.0)	(12.5)	(70.7)	(23.9)	(3.6)	(35.3)	(15.0)		
Zinc	2.8	1.5*	1.4*	1.5*	2.1	1.8*	2.0*	1.7*	1.9*	1.3*	0.024	0.007
	(0.2)	(0.2)	(0.1)	(0.3)	(0.4)	(0.4)	(0.3)	(0.1)	(0.2)	(0.3)		

Data are mean and (standard error), n=4. In rows * denotes LFH treatments significantly different from the control. In rows different letters denote significant differences, where upper case letters denote a significant difference between stockpile size and lower case letters denote a significant difference between burial depths. Significant difference at $p \leq 0.05$. [2]rank transformed for data analysis.

Table 5.5. Mean cation exchange capacity (meq 100 g^{-1}) and exchangeable cations (meq 100 g^{-1}) for burial depths after 16 months of storage in large and small stockpiles.

Species	Control	Large Stockpile					Small Stockpile				p Values One Way ANOVA	
		0.05 m	1.0 m	2.0 m	4.0 m	6.0 m	0.05 m	1.0 m	2.0 m	3.0 m	Large	Small
Cation exchange capacity	11.44 (3.84)	6.75 (1.98)	6.08 (1.62)	6.25 (1.80)	6.53 (1.69)	6.35 (2.32)	6.88 (1.70)	6.38 (1.25)	6.65 (2.26)	5.18 (1.31)	0.572	0.388
Calcium	5.3 (2.16)	5.15 (1.79)	4.08 (1.48)	4.6 (2.10)	4.58 (1.90)	3.98 (1.76)	4.53 (1.47)	3.88 (1.23)	4.03 (1.43)	2.78 (0.66)	0.994	0.808
Magnesium	1.05 (0.61)	0.98 (0.71)	0.68 (0.50)	0.75 (0.60)	0.73 (0.57)	0.65 (0.50)	0.95 (0.55)	0.75 (0.50)	0.8 (0.52)	0.58 (0.43)	0.994	0.973
Potassium	0.2 (0.10)	0.15 (0.10)	0.15 (0.05)	0.2 (0.08)	0.25 (0.05)	0.18 (0.10)	0.33 (0.15)	0.13 (0.08)	0.18 (0.10)	0.05 (0.05)	0.958	0.442
Sodium	0.01 (0.01)	0.07 (0.06)	0.07 (0.06)	0.13 (0.12)	0.13 (0.12)	0.13 (0.12)	0 (0.00)	0 (0.00)	0.05 (0.05)	0 (0.00)	0.995^2	0.572^2

Data are mean and (standard error), n=4. In rows * denotes LFH treatments significantly different from the control. In rows different letters denote significant differences, where upper case letters denote a significant difference between stockpile size and lower case letters denote a significant difference between burial depths. Significant difference at $p \leq 0.05$. [2] rank transformed for data analysis.

Table 5.6. Summary of p values from two way ANOVA for soil chemical properties after 8 months of storage.

Parameter	Size	Depth	Size x Depth
pH[1]	0.218	0.987	0.975
Electrical conductivity [2]	0.363	0.873	0.841
Sodium adsorption ratio	0.013	0.772	0.965
Total carbon	0.330	0.932	0.990
Total nitrogen	0.156	0.979	0.957
Available ammonium[2]	0.012	0.134	0.613
Available nitrate[2]	0.368	0.920	0.934
Available phosphorous	0.506	0.081	0.872
Available potassium	0.309	0.670	0.839
Available sulphate[1]			
Available calcium[2]	0.336	0.877	0.954
Soluble chloride[2]	0.892	0.690	0.802
Soluble magnesium[2]	0.523	0.858	0.966
Soluble potassium[2]	0.001	0.023	0.317
Soluble sodium	0.947	0.999	0.881
Soluble sulphate[2]	0.965	0.823	0.731
Extractable boron	0.581	0.999	0.942
Available copper	0.001	0.979	0.905
Available iron	0.518	0.361	0.836
Available manganese[2]	0.001	0.000	0.092
Available zinc[2]	0.800	0.941	0.699

[1] no analysis conducted; [2] rank transformed for data analysis.

Table 5.7. Summary of p values from two way ANOVA for soil chemical properties after 16 months of storage

Parameter	Size	Depth	Size x Depth
pH	0.477	0.779	0.999
Electrical conductivity[1]	-	-	-
Sodium adsorption ratio	0.012	0.051	0.554
Total carbon	0.291	0.524	0.973
Total nitrogen	0.951	0.427	0.456
Available ammonium	0.832	0.028	0.919
Available nitrate[2]	0.139	0.000	0.041
Available phosphorous	0.348	0.285	0.892
Available potassium	0.623	0.701	0.732
Available sulphate[2]	0.231	0.192	0.291
Soluble chloride[2]	0.165	0.793	0.260
Soluble calcium[2]	0.070	0.034	0.984
Soluble magnesium[2]	0.151	0.090	0.980
Soluble potassium[2]	0.071	0.109	0.884
Soluble sodium	0.546	0.952	0.697
Soluble sulphate[1]	-	-	-
Extractable boron	0.652	0.902	0.983
Exchangeable copper	0.229	0.709	0.829
Exchangeable iron[2]	0.317	0.194	0.208
Exchangeable manganese[2]	0.117	<.0.001	0.002
Exchangeable zinc	0.079	0.199	0.930
Cation exchange capacity	0.853	0.987	0.997
Exchangeable calcium	0.721	0.961	0.989
Exchangeable magnesium	0.941	0.993	0.995
Exchangeable potassium	0.574	0.528	0.448
Exchangeable sodium[1]	-	-	-

[1] no analysis conducted; [2] rank transformed for data analysis.

Table 5.8. Mean percent seed viability of grasses for burial depths after 8 months of storage in large and small stockpiles.

Species	Control	Large Stockpile					Small Stockpile				p Values	
		0.05 m	1.0 m	2.0 m	4.0 m	6.0 m	0.05 m	1.0 m	2.0 m	3.0 m	One Way ANOVA Large	Small
Agropyron trachycaulum	73 (5.5)	0* (0.0)	48 (9.4)	38* (13.1)	15* (15.0)	26* (12.5)	31 (17.9)	40 (8.5)	39 (13.7)	43 (4.1)	0.002	0.094[2]
Bromus ciliatus	58 (5.8)	15* (13.7)	41 (6.2)	15* (10.0)	11* (11.0)	10* (10.0)	38 (9.0)	38 (8.4)	50 (11.4)	43 (4.4)	0.012	0.391
Carex anea	94 (2.6)	87 (6.4)	95 (2.5)	75 (17.3)	24 (24.0)	75 (18.4)	88 (4.9)	93 (2.5)	86 (4.8)	90 (2.6)	0.316[2]	0.519
Elymus innovatus	54 (8.7)	3* (3.0)	7* (7.0)	3* (3.0)	11* (11.0)	9* (7.7)	1* (1.0)	0* (0.0)	8* (8.0)	18* (5.3)	0.001	<0.0011
Oryzopsis pungens	91 (4.1)	58 (11.8)	59 (19.8)	23 (19.2)	21 (21.0)	24 (21.4)	68 (6.7)	39* (14.8)	83 (1.9)	84 (2.3)	0.060	0.002

Data are mean and (standard error), n=4. In rows * denotes LFH treatments significantly different from the control. In rows different letters denote significant differences, where upper case letters denote a significant difference between stockpile size and lower case letters denote a significant difference between burial depths. Significant difference at $p \leq 0.05$. [2] rank transformed for data analysis.

Table 5.9. Mean percent seed viability of grasses for burial depths after 16 months of storage in large and small stockpiles.

Species	Control	Large Stockpile					Small Stockpile				p Values	
		0.05 m	1.0 m	2.0 m	4.0 m	6.0 m	0.05 m	1.0 m	2.0 m	3.0 m	One Way ANOVA Large	Small
Agropyron trachycaulum	73 (5.5)	0* (0.0)	11* (7.5)	14* (14.0)	0* (0.0)	0* (0.0)	0* (0.0)	4* (4.0)	4* (4.0)	1* (1.0)	<0.001[2]	0.001[2]
Bromus ciliatus	58 (5.8)	0* (0.0)	10* (8.7)	7* (7.0)	0* (0.0)	0* (0.0)	0* (0.0)	10* (10.0)	0* (0.0)	0* (0.0)	<0.001[2]	<0.001[2]
Carex anea	94 (2.6)	76* (4.9)	90 (3.8)	26* (17.5)	0* (0.0)	16* (14.0)	88 (5.9)	98 (2.0)	57 (23.0)	48 (24.7)	<0.001[2]	0.200[2]
Elymus innovatus	54 (8.7)	0* (0.0)	0* (0.0)	6* (6.0)	0* (0.0)	0* (0.0)	0* (0.0)	0* (0.0)	0* (0.0)	0* (0.0)	<0.001[2]	<0.001[2]
Oryzopsis pungens	91 (4.1)	23* (4.1)	30* (10.5)	0* (0.0)	0* (0.0)	0* (0.0)	34* (11.0)	9* (5.7)	11* (6.4)	0* (0.0)	<0.001[2]	<0.001[2]

Data are mean and (standard error), n=4. In rows* denotes LFH treatments significantly different from the control. In rows different letters denote significant differences, where upper case letters denote a significant difference between stockpile size and lower case letters denote a significant difference between burial depths. Significant difference at $p \leq 0.05$. [2] rank transformed for data analysis.

Table 5.10. Mean percent seed viability of herbaceous plants for burial depths after 8 months of storage in large and small stockpiles.

Species	Control	Large Stockpile					Small Stockpile				p Values	
		0.05 m	1.0 m	2.0 m	4.0 m	6.0 m	0.05 m	1.0 m	2.0 m	3.0 m	One Way ANOVA Large	Small
Anemone multifida	63	16	54	20	19	0	39	23	45	51	0.068	0.152[2]
	(4.4)	(5.9)	(14.8)	(17.4)	(19.0)	(12.5)	(12.9)	(9.0)	(16.8)	(3.0)		
Anemone patens	70	18*	23*	13*	7*	6*	26*	9*	16*	14*	<0.001	<0.001
	(2.0)	(6.2)	(10.9)	(13.0)	(7.0)	(6.0)	(9.6)	(5.3)	(11.0)	(4.8)		
Aralia nudicaulis	59	10*	6*	4*	4*	2*	15*	14*	10*	11*	<0.001	<0.001
	(5.7)	(1.2)	(3.5)	(4.0)	(4.0)	(2.0)	(1.9)	(6.0)	(4.2)	(1.9)		
Cornus canadensis	82	82	86	56	25	55*	81	80	82	87	0.010[2]	0.246[2]
	(2.6)	(1.2)	(1.2)	(18.8)	(21.2)	(18.4)	(4.4)	(0.0)	(1.2)	(1.9)		
Dracocephalum	97	98	97	92	86	94	94	99	98	98	0.057	0.307
parviflorum	(1.0)	(2.0)	(1.0)	(3.7)	(4.8)	(2.0)	(2.6)	(1.0)	(1.2)	(2.0)		
Fragaria	88	66	69	30	20	40	75.5	72	66	78	0.074	0.378[2]
virginiana	(2.3)	(12.9)	(15.3)	(19.9)	(20.0)	(22.0)	(9.5)	(8.2)	(18.2)	(3.8)		
Geranium	97	78*	77*	79*	84*	84*	79*	56*	78*	84*	0.020[2]	<0.001
bicknellii	(1.9)	(2.6)	(11.0)	(5.7)	(3.7)	(1.6)	(1.0)	(5.7)	(7.4)	(1.6)		
Rubus pubescens	87	62*a	46*b	12*c	6*d	16*d	68a	44b	32*c	56*a	<0.001	<0.001[2]
	(3.4)	(5.8)	(9.9)	(9.5)	(6.0)	(9.9)	(2.8)	(13.5)	(12.5)	(5.9)		
Vicia americana	84	30*	60	43*	20*	41*	20	68	54	59	0.003	0.092[2]
	(4.3)	(7.4)	(12.1)	(7.5)	(9.1)	(13.7)	(7.8)	(18.8)	(21.5)	(10.0)		
Maianthemum	90	30*	84	26*	21*	23*	82	64	68	68	0.012	0.331[2]
canadense	(2.6)	(10.9)	(7.1)	(21.0)	(21.0)	(21.7)	(3.5)	(21.5)	(22.7)	(22.7)		
Potentilla	59	31*	30*	11*	10*	12*	31	33	28	35	0.002	0.054
tridentata	(4.4)	(3.4)	(6.6)	(6.2)	(10.0)	(12.0)	(1.9)	(9.0)	(9.9)	(7.5)		

Data are mean and (standard error), n=4. In rows* denotes LFH treatments significantly different from the control. In rows different letters denote significant differences, where upper case letters denote a significant difference between stockpile size and lower case letters denote a significant difference between burial depths. Significant difference at $p \leq 0.05$. [2] rank transformed for data analysis.

Table 5.11. Mean percent seed viability of herbaceous plants for burial depths after 16 months of storage in large and small stockpiles.

Species	Control	Large Stockpile					Small Stockpile				p Values	
		0.05 m	1.0 m	2.0 m	4.0 m	6.0 m	0.05 m	1.0 m	2.0 m	3.0 m	One Way ANOVA Large	Small
Anemone multifida	63	10*	40	13*	0*	0*	25*	2*	21*	0*	<0.001[2]	0.002[2]
	(4.4)	(6.6)	(13.6)	(13.0)	(0.0)	(0.0)	(13.0)	(2.0)	(13.4)	(0.0)		
Anemone patens	70	0*	6*	4*	0*	0*	1*	2*	1*	0*	<0.001[2]	0.001[2]
	(2.0)	(0.0)	(4.8)	(4.0)	(0.0)	(0.0)	(1.0)	(2.0)	(1.0)	(0.0)		
Aralia nudicaulis	59	8*	5*	8*	0*	0*	4*	6*	0*	0*	<0.001[2]	<0.001[2]
	(5.7)	(4.9)	(5.0)	(8.0)	(0.0)	(0.0)	(4.0)	(3.8)	(0.0)	(0.0)		
Cornus canadensis	82	66[a]	34*[b]	6*[c]	6*[d]	13*[d]	67*[a]	37*[b]	22*[c]	0*[d]	<0.001[2]	<0.001[2]
	(2.6)	(3.5)	(13.1)	(3.8)	(6.0)	(13.0)	(5.3)	(14.7)	(8.1)	(0.0)		
Dracocephalum	97	97[a]	99[a]	97[a]	89*[b]	96[ab]	96[a]	98[a]	96[a]	98[a]	0.034[2]	0.698
parviflorum	(1.0)	(1.0)	(1.0)	(1.9)	(3.4)	(0.0)	(1.6)	(1.2)	(1.6)	(1.2)		
Fragaria	88	25*[a]	61[a]	14*	5*[b]	3*[b]	44.5*[a]	43*[a]	3*[b]	1*[b]	<0.001[2]	<0.001[2]
virginiana	(2.3)	(5.0)	(11.5)	(14.0)	(5.0)	(3.0)	(10.7)	(17.4)	(3.0)	(1.0)		
Geranium	97	86[a]	33[b]	79[a]	83[a]	88[a]	76[a]	39*[b]	55[a]	68[a]	0.063[2]	0.021
bicknellii	(1.9)	(1.2)	(22.4)	(6.8)	(3.0)	(5.3)	(11.4)	(18.4)	(22.6)	(22.7)		
Rubus pubescens	87	50	13*	2*	0*	1*	73	13*	9*	2*	<0.001[2]	<0.001[2]
	(3.4)	(23.1)	(13.0)	(2.0)	(0.0)	(1.0)	(4.4)	(13.0)	(9.0)	(2.0)		
Vicia americana	84	15*	30*	12*	14*	35*	18*	39*	18*	43*	0.020[2]	0.011
	(4.3)	(8.7)	(11.6)	(9.5)	(3.5)	(13.9)	(14.3)	(15.3)	(8.4)	(15.6)		
Maianthemum	90	46	31*	15*	0*	0*	81	26*	0*	0*	<0.001[2]	<0.001[2]
canadense	(2.6)	(24.4)	(17.3)	(15.0)	(0.0)	(0.0)	(6.2)	(22.2)	(0.0)	(0.0)		
Potentilla	59	20*	7*	10*	0*	0*	14*	6*	3*	0*	<0.001[2]	<0.001[2]
tridentata	(4.4)	(3.7)	(3.4)	(10.0)	(0.0)	(0.0)	(3.5)	(3.8)	(1.9)	(0.0)		

Data are mean and (standard error), n=4. In rows* denotes LFH treatments significantly different from the control. In rows different letters denote significant differences, where upper case letters denote a significant difference between stockpile size and lower case letters denote a significant difference between burial depths. Significant difference at $p \leq 0.05$. [2] rank transformed for data analysis.

Table 5.12. Mean percent seed viability of woody plants for burial depths after 8 months of storage in large and small stockpiles.

Species	Control	Large Stockpile					Small Stockpile				p Values	
		0.05 m	1.0 m	2.0 m	4.0 m	6.0 m	0.05 m	1.0 m	2.0 m	3.0 m	One Way ANOVA Large	Small
Alnus crispa	18	1*	4*	0*	2*	2*	6	4	9	3	0.002[2]	0.059
	(2.0)	(1.0)	(2.3)	(0.0)	(2.0)	(2.0)	(2.6)	(4.0)	(5.7)	(1.9)		
Arctostaphylos	60	42	59	49	23	49	46	65	44*	50	0.320	0.028
uva-ursi	(4.3)	(8.1)	(11.1)	(13.5)	(17.0)	(13.9)	(7.7)	(3.4)	(4.3)	(2.0)		
Prunus	88	86	49	28*	22*	28*	86	68	62	78	0.018	0.382[2]
pensylvanica	(2.8)	(2.6)	(10.8)	(20.3)	(22.0)	(20.8)	(3.5)	(17.5)	(21.1)	(3.5)		
Ribes	98	86*	94	58	17*	61*	93	88	72	93	0.001[2]	0.203[2]
hudsonianum	(1.2)	(2.6)	(2.0)	(24.3)	(17.0)	(20.4)	(1.9)	(4.3)	(24.1)	(3.0)		
Rosa acicularis	56	31	24	34	18	34	36	33	31	37	0.281	0.086
	(8.2)	(4.7)	(5.9)	(11.6)	(18.0)	(12.4)	(4.9)	(4.4)	(9.0)	(3.0)		
Rubus idaeus	92	86	85	47*	22*	57*	78*	67*	64*	80*	0.005[2]	0.030[2]
	(2.8)	(3.8)	(1.9)	(18.6)	(20.7)	(19.6)	(2.6)	(11.7)	(20.0)	(2.3)		
Shepherdia	93	74[a]	25*[a]	20*[b]	8*[b]	12*[b]	87[a]	74*[a]	25*[b]	49*[a]	0.002	0.004[2]
canadensis	(1.9)	(9.6)	(23.7)	(20.0)	(8.0)	(12.0)	(2.5)	(9.0)	(19.8)	(13.7)		
Vaccinium	77	45	37*	31*	14*	24*	64*	31*	11*	15*	0.023	<0.001
myrtilloides	(5.0)	(4.4)	(10.0)	(15.2)	(14.0)	(16.1)	(4.9)	(2.5)	(3.8)	(1.9)		
Vaccinium vitis-	89	83	70	34	22	31	83	82	66	86	0.106[2]	0.700
idea	(4.1)	(3.4)	(12.7)	(20.7)	(22.0)	(19.5)	(1.9)	(2.0)	(22.1)	(2.6)		
Virburnum edule	88	86	79	66	40	73	87	63	65	86	0.064[2]	0.202
	(1.6)	(1.2)	(7.2)	(14.1)	(14.9)	(7.2)	(5.3)	(21.1)	(9.8)	(6.2)		
Pinus banksiana	87	57	-	57	-	25	75	-	-	68	0.126	0.112[2]
	(2.5)	(15.4)	-	(15.4)	-	(25.0)	(3.4)	-	-	(11.2)		

Data are mean and (standard error), n=4. In rows* denotes LFH treatments significantly different from the control. In rows different letters denote significant differences, where upper case letters denote a significant difference between stockpile size and lower case letters denote a significant difference between burial depths. Significant difference at $p \leq 0.05$. [2] rank transformed for data analysis.

Table 5.13. Mean percent seed viability of woody plants for burial depths after 16 months of storage in large and small stockpiles.

Species	Control	Large Stockpile					Small Stockpile				p Values	
		0.05 m	1.0 m	2.0 m	4.0 m	6.0 m	0.05 m	1.0 m	2.0 m	3.0 m	One Way ANOVA Large	Small
Alnus crispa	18	4*	1*	0*	0*	0*	4*	0*	0*	0*	<0.001[2]	<0.001[2]
	(2.0)	(2.8)	(1.0)	(0.0)	(0.0)	(0.0)	(2.8)	(0.0)	(0.0)	(0.0)		
Arctostaphylos uva-ursi	60	13*	0*	0*	0*	0*	17*	6*	0*	0*	<0.001[2]	0.002[2]
	(4.3)	(13.0)	(0.0)	(0.0)	(0.0)	(0.0)	(17.0)	(6.0)	(0.0)	(0.0)		
Prunus pensylvanica	88	82[a]	25[*b]	12[*bc]	2[*c]	0[*c]	49[*a]	22[*b]	11[*bc]	3[*c]	<0.001[2]	0.002[2]
	(2.8)	(2.6)	(13.7)	(10.7)	(2.0)	(0.0)	(16.8)	(12.9)	(4.1)	(3.0)		
Ribes hudsonianum	98	21*	0*	0*	0*	0*	4*	0*	0*	0*	<0.001[2]	<0.001[2]
	(1.2)	(9.1)	(0.0)	(0.0)	(0.0)	(0.0)	(2.8)	(0.0)	(0.0)	(0.0)		
Rosa acicularis	56	0*	14*	0*	11*	6*	14*	6*	5*	6*	0.002[2]	<0.001
	(8.2)	(0.0)	(8.7)	(0.0)	(11.0)	(6.0)	(8.2)	(6.0)	(5.0)	(3.5)		
Rubus idaeus	92	67[*a]	64[a]	21[*b]	11[*b]	0[*b]	78[a]	60[a]	20[*b]	24[*ab]	<0.001[2]	0.014
	(2.8)	(9.4)	(21.4)	(21.0)	(11.0)	(0.0)	(2.6)	(20.1)	(20.0)	(18.0)		
Shepherdia canadensis	93	49	10*	9*	0*	0*	47*	0*	0*	0*	<0.001[2]	<0.001[2]
	(1.9)	(14.8)	(6.0)	(5.3)	(0.0)	(0.0)	(14.8)	(0.0)	(0.0)	(0.0)		
Vaccinium myrtilloides	77	39*	18*	15*	0*	0*	34*	12*	0*	6*	<0.001[2]	<0.001[2]
	(5.0)	(7.0)	(10.5)	(15.0)	(0.0)	(0.0)	(2.6)	(12.0)	(0.0)	(3.5)		
Vaccinium vitis-idea	89	64*	43*	16*	0*	0*	49*	42*	5*	0*	<0.001[2]	<0.001
	(4.1)	(3.3)	(19.0)	(16.0)	(0.0)	(0.0)	(8.7)	(8.7)	(5.0)	(0.0)		
Virburnum edule	88	58*[a]	20[*b]	5[*b]	1[*b]	18[*b]	72[* a]	20[*b]	14[*b]	6[*b]	0.001[2]	<0.001[2]
	(1.6)	(6.6)	(17.4)	(5.0)	(1.0)	(18.0)	(4.0)	(20.0)	(14.0)	(6.0)		
Pinus banksiana	87	49.3*	-	2*	-	0*	62*	-	-	0*	<0.001[2]	<0.001[2]
	(2.5)	(19.6)	-	(2.0)	-	(0.0)	(13.3)	-	-	(0.0)		

Data are mean and (standard error), n=4. In rows* denotes LFH treatments significantly different from the control. In rows different letters denote significant differences, where upper case letters denote a significant difference between stockpile size and lower case letters denote a significant difference between burial depths. Significant difference at $p \leq 0.05$. [2] rank transformed for data analysis.

Table 5.14. Summary of p values from two way ANOVA for seed viability after 8 months of storage.

Species	Size	Depth	Size x Depth
Agropyron trachycaulum[1]	-	-	-
Bromus ciliatus	0.029	0.557	0.154
Carex anea[2]	0.635	0.307	0.948
Elymus innovatus[1]	-	-	-
Oryzopsis pungens [2]	0.245	0.526	0.058
Alnus crispa[1]	-	-	-
Arctostaphylos uva-ursi[1]	-	-	-
Prunus pensylvanica[1]	0.198	0.132	0.700
Ribes hudsonianum[1]	-	-	-
Rosa acicularis	0.638	0.839	0.812
Rubus idaeus[2]	0.250	0.143	0.049
Shepherdia canadensis[2]	0.054	0.010	0.621
Vaccinium myrtilloides[1]	-	-	-
Vaccinium vitis- idea[2]	0.227	0.732	0.408
Virburnum edule[2]	0.574	0.084	0.825
Pinus banksiana[1]	-	-	-
Anemone multifida	0.608	0.724	0.077
Anemone patens	0.888	0.691	0.423
Aralia nudicaulis[1]	-	-	-
Cornus canadensis[1]	-	-	-
Dracocephalum parviflorum[2]	0.593	0.452	0.151
Fragaria virginiana	0.319	0.551	0.470
Geranium bicknellii[1]	-	-	-
Rubus pubescens	0.289	<0.001	0.479
Vicia americana	0.779	0.055	0.684
Maianthemum canadense	0.082	0.305	0.084
Potentilla tridentata	0.317	0.312	0.535

[1] no analysis conducted; [2] rank transformed for data analysis.

Table 5.15. Summary of p values from two way ANOVA for seed viability after 16 months of storage

Species	Size	Depth	Size x Depth
Agropyron trachycaulum[1]	-	-	-
Bromus ciliatus[1]	-	-	-
Carex anea [1]	-	-	-
Elymus innovatus[1]	-	-	-
Oryzopsis pungens[1]	-	-	-
Alnus crispa[1]	-	-	-
Arctostaphylos uva-ursi[1]	-	-	-
Prunus pensylvanica[2]	0.510	0.000	0.165
Ribes hudsonianum[1]	-	-	-
Rosa acicularis [1]	-	-	-
Rubus idaeus[2]	0.905	0.008	0.741
Shepherdia canadensis[1]	-	-	-
Vaccinium myrtilloides[1]	-	-	-
Vaccinium vitis- idea[1]	-	-	-
Virburnum edule[2]	0.709	0.003	0.736
Pinus banksiana[1]	-	-	-
Anemone multifida[1]	-	-	-
Anemone patens [1]	-	-	-
Aralia nudicaulis[1]	-	-	-
Cornus canadensis[2]	0.219	<0.001	0.463
Dracocephalum parviflorum[2]	0.349	0.032	0.991
Fragaria virginiana[2]	0.560	0.000	0.270
Geranium bicknellii[2]	0.799	0.064	0.967
Rubus pubescens[1]	-	-	-
Vicia americana[2]	0.609	0.389	0.903
Maianthemum canadense[1]	-	-	-
Potentilla tridentata[1]	-	-	-

[1] no analysis conducted; [2] rank transformed for data analysis.

Table 5.16. Mean percent germination of grasses for burial depths after 8 months of storage in large and small stockpiles.

Species	Control	Large Stockpile					Small Stockpile				p Values	
		0.05 m	1.0 m	2.0 m	4.0 m	6.0 m	0.05 m	1.0 m	2.0 m	3.0 m	One Way ANOVA Large	Small
Agropyron trachycaulum	72 (6.7)	0* (0.0)	42 12.49	13* (13.0)	15* (15.0)	18* (14.3)	18* (11.8)	33* (3.0)	35* (11.7)	40* (4.0)	0.004	0.005
Bromus ciliatus	58 (2.6)	1^{*B} (1.0)	35^{B} (11.9)	15^{*B} (10.0)	10^{*B} (10.0)	10^{*B} (10.0)	38^{A} (9.0)	36^{A} (10.2)	47^{A} (15.7)	37^{A} (8.2)	0.002	0.506
Carex anea	93 (3.0)	83 (6.6)	95 (2.5)	73 (16.8)	22 (22.0)	72 (21.4)	91 (4.1)	91 (3.4)	70 (17.0)	71 (17.3)	0.077[2]	0.402[2]
Elymus innovatus	55 (5.3)	3* (3.0)	6* (3.8)	3* (3.0)	11* (11.0)	9* (7.7)	0* (0.0)	0* (0.0)	8* (8.0)	17* (5.5)	<0.001	<0.001[2]
Oryzopsis pungens	66 (2.6)	40^{*a} (2.8)	5^{*b} (3.0)	10^{*b} (6.6)	5^{*b} (5.0)	7^{*b} (7.0)	31^{*a} (5.3)	20^{*b} (6.3)	27^{*b} (9.1)	41^{*a} (7.0)	<0.001	0.001

Data are mean and (standard error), n=4. In rows* denotes LFH treatments significantly different from the control. In rows different letters denote significant differences, where upper case letters denote a significant difference between stockpile size and lower case letters denote a significant difference between burial depths. Significant difference at $p \leq 0.05$. [2] rank transformed for data analysis.

Table 5.17. Mean percent germination of grasses for burial depths after 16 months of storage in large and small stockpiles.

Species	Control	Large Stockpile					Small Stockpile				p Values	
		0.05 m	1.0 m	2.0 m	4.0 m	6.0 m	0.05 m	1.0 m	2.0 m	3.0 m	One Way ANOVA Large	Small
Agropyron trachycaulum	72 (6.7)	0* (0.0)	0* (0.0)	7* (7.0)	0* (0.0)	0* (0.0)	0* (0.0)	3* (1.9)	7* (7.0)	1* (1.0)	<0.001[2]	0.001[2]
Bromus ciliatus	58 (2.6)	0* (0.0)	11* (9.7)	2* (2.0)	0* (0.0)	0* (0.0)	2* (1.2)	11* (11.0)	1* (1.0)	0* (0.0)	<0.001[2]	0.001[2]
Carex anea	93 (3.0)	81 (5.5)	85 (6.0)	1* (1.0)	3* (3.0)	12* (12.0)	88 (5.9)	89 (7.2)	57 (23.0)	43 (24.9)	<0.001[2]	0.348[2]
Elymus innovatus	55 (5.3)	0* (0.0)	0* (0.0)	2* (2.0)	0* (0.0)	0* (0.0)	0* (0.0)	0* (0.0)	0* (0.0)	0* (0.0)	<0.001[2]	<0.001[2]
Oryzopsis pungens	66 (2.6)	25* (5.0)	28* (10.2)	0* (0.0)	0* (0.0)	0* (0.0)	20* (7.1)	3* (3.0)	0* (0.0)	0* (0.0)	<0.001[2]	<0.001[2]

Data are mean and (standard error), n=4. In rows* denotes LFH treatments significantly different from the control. In rows different letters denote significant differences, where upper case letters denote a significant difference between stockpile size and lower case letters denote a significant difference between burial depths. Significant difference at $p \leq 0.05$. [2] rank transformed for data analysis.

Table 5.18. Mean percent germination of herbaceous plants for burial depths after 8 months of storage in large and small stockpiles.

Species	Control	Large Stockpile					Small Stockpile				p Values	
		0.05 m	1.0 m	2.0 m	4.0 m	6.0 m	0.05 m	1.0 m	2.0 m	3.0 m	One Way ANOVA Large	Small
Anemone multifida	38 (11.8)	7 (3.0)	30 (12.7)	10 (10.0)	8 (8.0)	10 (10.0)	39 (14.4)	4 (2.8)	26 (10.6)	23 (7.2)	0.152	0.156
Anemone patens	51 (5.5)	9* (7.7)	19* (7.5)	1* (1.0)	1* (1.0)	2* (2.0)	17* (7.4)	12* (5.2)	12* (12.0)	13* (4.4)	0.002[2]	0.008
Aralia nudicaulis	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	-	-
Cornus canadensis	0 (0.0)	0 (0.0)	1 (1.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0.446[2]	-
Dracocephalum parviflorum	9 (3.4)	3 (1.0)	7 (1.9)	2* (2.0)	0* (0.0)	0* (0.0)	2 (1.2)	1 (1.0)	1 (1.0)	4 (2.3)	0.005[2]	0.234[2]
Fragaria virginiana	62 (8.7)	48 (9.4)	55 (13.9)	18* (13.2)	17* (15.7)	16* (9.2)	71 (5.3)	54 (9.3)	51 (16.2)	51 (5.7)	0.032	0.562
Geranium bicknellii	5 (3.8)	2 (2.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	1 (1.0)	0.167[2]	0.185[2]
Rubus pubescens	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	2 (2.0)	0 (0.0)	0 (0.0)	0 (0.0)	-	-
Vicia americana	24 (4.3)	0* (0.0)	3* (3.0)	0* (0.0)	1* (1.0)	2* (2.0)	0* (0.0)	1* (1.0)	0* (0.0)	4* (1.6)	<0.001[2]	<0.001[2]
Maianthemum canadense	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	-	-
Potentilla tridentata	21 (5.5)	14*[a] (2.6)	5*[b] (1.0)	2*[b] (1.2)	1*[b] (1.0)	3*[b] (3.0)	18[a] (3.8)	4*[b] (1.6)	7*[b] (4.4)	9*[a] (2.5)	<0.001[2]	0.029

Data are mean and (standard error), n=4. In rows* denotes LFH treatments significantly different from the control. In rows different letters denote significant differences, where upper case letters denote a significant difference between stockpile size and lower case letters denote a significant difference between burial depths. Significant difference at $p \leq 0.05$. [2] rank transformed for data analysis.

Table 5.19. Mean percent germination of herbaceous plants for burial depths after 8 months of storage in large and small stockpiles.

Species	Control	Large Stockpile					Small Stockpile				p Values	
		0.05 m	1.0 m	2.0 m	4.0 m	6.0 m	0.05 m	1.0 m	2.0 m	3.0 m	One Way ANOVA Large	Small
Anemone multifida	38 (11.8)	0* (0.0)	18* (10.9)	0* (0.0)	0* (0.0)	0* (0.0)	10* (10.0)	7* (7.0)	1* (1.0)	0* (0.0)	<0.001[2]	0.014[2]
Anemone patens	51 (5.5)	0* (0.0)	0* (0.0)	0* (0.0)	0* (0.0)	0* (0.0)	0* (0.0)	0* (0.0)	0* (0.0)	0* (0.0)	<0.001[2]	<0.001[2]
Aralia nudicaulis	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	-	-
Cornus canadensis	0 (0.0)	2 (1.2)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	1 (1.0)	0 (0.0)	0 (0.0)	0 (0.0)	-	-
Dracocephalum parviflorum	9 (3.4)	3 (1.9)	3 (1.9)	0* (0.0)	0* (0.0)	0* (0.0)	2 (1.2)	1* (1.0)	0* (0.0)	0* (0.0)	0.025[2]	0.035[2]
Fragaria virginiana	62 (8.7)	26* (13.1)	38 (15.4)	7* (7.0)	0* (0.0)	0* (0.0)	35* (4.4)	18* (10.5)	0* (0.0)	0* (0.0)	<0.001[2]	<0.001[2]
Geranium bicknellii	5 (3.8)	0* (0.0)	0* (0.0)	0* (0.0)	0* (0.0)	0* (0.0)	0* (0.0)	0* (0.0)	0* (0.0)	0* (0.0)	0.039[2]	0.049[2]
Rubus pubescens	0 (0.0)	4 (4.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	-	-
Vicia americana	24 (4.3)	0* (0.0)	0* (0.0)	0* (0.0)	0* (0.0)	0* (0.0)	0* (0.0)	0* (0.0)	0* (0.0)	0* (0.0)	<0.001[2]	<0.001[2]
Maianthemum canadense	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	-	-
Potentilla tridentata	21 (5.5)	7* (3.0)	0* (0.0)	0* (0.0)	0* (0.0)	0* (0.0)	6* (3.8)	0* (0.0)	2* (2.0)	0* (0.0)	<0.001[2]	<0.001[2]

Data are mean and (standard error), n=4. In rows* denotes LFH treatments significantly different from the control. In rows different letters denote significant differences, where upper case letters denote a significant difference between stockpile size and lower case letters denote a significant difference between burial depths. Significant difference at $p \leq 0.05$. [2] rank transformed for data analysis.

Table 5.20. Mean percent germination of woody plants for burial depths after 8 months of storage in large and small stockpiles.

Species	Control	Large Stockpile					Small Stockpile				p Values	
		0.05 m	1.0 m	2.0 m	4.0 m	6.0 m	0.05 m	1.0 m	2.0 m	3.0 m	One Way ANOVA	
											Large	Small
Alnus crispa	13	5*	4*	3*	2*	1*	6	2	6	3	0.010	0.236
	(1.9)	(1.9)	(2.3)	(3.0)	(2.0)	(1.0)	(3.5)	(2.0)	(6.0)	(1.9)		
Arctostaphylos	0	0	0	0	0	0	0	0	0	0	-	-
uva-ursi	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)		
Prunus	0	0	0	0	0	0	0	0	0	0	-	-
pensylvanica	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)		
Ribes	16	13	8	5	0*	1*	5	6	0*	1*	0.031[2]	0.016[2]
hudsonianum	(9.7)	(4.4)	(4.3)	(3.8)	(0.0)	(1.0)	(1.9)	(1.2)	(0.0)	(1.0)		
Rosa acicularis	0	0	0	0	0	0	0	0	0	0	-	-
	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)		
Rubus idaeus	0	3	1	0	0	0	0	0	0	1	0.564[2]	0.438[2]
	(0.0)	(3.0)	(1.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(1.0)		
Shepherdia	0	5*	1	0	0	0	3	3	0	0	0.007[2]	0.573[2]
canadensis	(0.0)	(2.5)	(1.0)	(0.0)	(0.0)	(0.0)	(3.0)	(3.0)	(0.0)	(0.0)		
Vaccinium	41	20*	20*	12*	3*	11*	13*	11*	5*	8*	0.005[2]	<0.001[2]
myrtilloides	(2.5)	(5.7)	(8.2)	(6.3)	(3.0)	(6.4)	(3.0)	(3.0)	(1.9)	(1.6)		
Vaccinium vitis-	32	2*	10*	4*	0*	3*	2	3*	3*	7*	0.002[2]	<0.001[2]
idea	(3.7)	(1.2)	(4.2)	(4.0)	(0.0)	(1.9)	(2.0)	(1.9)	(3.0)	(1.9)		
Virburnum edule	0	0	0	0	0	0	0	0	0	0	-	-
	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)		
Pinus banksiana	82	53	-	47*	-	20*	67*	-	-	55*	<0.001[2]	<0.001[2]
	(3.8)	(15.8)	-	(14.5)	-	(20.0)	(3.4)	-	-	(9.3)		

Data are mean and (standard error), n=4. In rows* denotes LFH treatments significantly different from the control. In rows different letters denote significant differences, where upper case letters denote a significant difference between stockpile size and lower case letters denote a significant difference between burial depths. Significant difference at $p \leq 0.05$. [2] rank transformed for data analysis.

Table 5.21. Mean percent germination of woody plants for burial depths after 16 months of storage in large and small stockpiles.

Species	Control	Large Stockpile					Small Stockpile				p Values	
		0.05 m	1.0 m	2.0 m	4.0 m	6.0 m	0.05 m	1.0 m	2.0 m	3.0 m	One Way ANOVA Large	Small
Alnus crispa	13	2*	0*	0*	0*	0*	4*	1*	0*	0*	<0.001[2]	0.002[2]
	(1.9)	(2.0)	(0.0)	(0.0)	(0.0)	(0.0)	(4.0)	(1.0)	(0.0)	(0.0)		
Arctostaphylos	0	0	0	0	0	0	0	0	0	0	-	-
uva-ursi	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)		
Prunus	0	0	0	0	0	0	0	0	0	0	-	-
pensylvanica	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)		
Ribes	16	17	0*	0*	0*	0*	6	0*	0*	0*	0.011[2]	0.0041
hudsonianum	(9.7)	(10.6)	(0.0)	(0.0)	(0.0)	(0.0)	(2.6)	(0.0)	(0.0)	(0.0)		
Rosa acicularis	0	0	0	0	0	0	0	0	0	0	-	-
	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)		
Rubus idaeus	0	1	0	0	0	0	0	0	0	0	0.446[2]	-
	(0.0)	(1.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)		
Shepherdia	0	16*	4	0	0	0	35*	0	0	0	0.009[2]	<0.001[2]
canadensis	(0.0)	(9.9)	(4.0)	(0.0)	(0.0)	(0.0)	(18.6)	(0.0)	(0.0)	(0.0)		
Vaccinium	41	10*	1*	0*	0*	0*	0*	1*	0*	0*	<0.001[2]	<0.001[2]
myrtilloides	(2.5)	(10.0)	(1.0)	(0.0)	(0.0)	(0.0)	(0.0)	(1.0)	(0.0)	(0.0)		
Vaccinium vitis-	32	55	41	14	0*	0*	43	38	4*	0*	0.002[2]	0.003[2]
idea	(3.7)	(10.8)	(17.9)	(14.0)	(0.0)	(0.0)	(14.4)	(8.7)	(4.0)	(0.0)		
Virburnum edule	0	0	0	0	0	0	0	0	0	0	-	-
	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)		
Pinus banksiana	82	55*	-	2*	-	0*	50*	-	-	0*	<0.001[2]	<0.001[2]
	(3.8)	(5.3)	-	(2.0)	-	(0.0)	(13.3)	-	-	(0.0)		

Data are mean and (standard error), n=4. In rows* denotes LFH treatments significantly different from the control. In rows different letters denote significant differences, where upper case letters denote a significant difference between stockpile size and lower case letters denote a significant difference between burial depths. Significant difference at $p \leq 0.05$. [2] rank transformed for data analysis.

Table 5.22. Summary of p values from two way ANOVA for seed viability after 8 months of storage

Species	Size	Depth	Size x Depth
Agropyron trachycaulum	0.253	0.204	0.313
Bromus ciliatus	0.009	0.665	0.182
Carex anea[2]	0.878	0.086	0.527
Elymus innovatus[1]	-	-	-
Oryzopsis pungens	0.136	0.002	0.078
Alnus crispa	0.785	0.861	0.699
Arctostaphylos uva-ursi[1]	-	-	-
Prunus pensylvanica[1]	-	-	-
Ribes hudsonianum[1]	-	-	-
Rosa acicularis[1]	-	-	-
Rubus idaeus[1]	-	-	-
Shepherdia canadensis[1]	-	-	-
Vaccinium myrtilloides[1]	-	-	-
Vaccinium vitis- idea	0.212	0.156	0.348
Virburnum edule[1]	-	-	-
Pinus banksiana[1]	-	-	-
Anemone multifida	-	-	-
Anemone patens[2]	0.537	0.273	0.601
Aralia nudicaulis[1]	-	-	-
Cornus canadensis[1]	-	-	-
Dracocephalum parviflorum[1]	-	-	-
Fragaria virginiana[1]	-	-	-
Geranium bicknellii[1]	-	-	-
Rubus pubescens[1]	-	-	-
Vicia americana[1]	-	-	-
Maianthemum canadense[1]	-	-	-
Potentilla tridentata[1]	-	-	-

[1] no analysis conducted; [2] rank transformed for data analysis.

Table 5.23. Summary of p values from two way ANOVA for seed viability after 16 months of storage

Species	Size	Depth	Size x Depth
Agropyron trachycaulum[1]	-	-	-
Bromus ciliatus[1]	-	-	-
Carex anea [1]	-	-	-
Elymus innovatus[1]	-	-	-
Oryzopsis pungens[1]	-	-	-
Alnus crispa[1]	-	-	-
Arctostaphylos uva-ursi[1]	-	-	-
Prunus pensylvanica[1]	-	-	-
Ribes hudsonianum[1]	-	-	-
Rosa acicularis[1]	-	-	-
Rubus idaeus[1]	-	-	-
Shepherdia canadensis[1]	-	-	-
Vaccinium myrtilloides[1]	-	-	-
Vaccinium vitis- idea[1]	-	-	-
Virburnum edule[1]	-	-	-
Pinus banksiana[2]	-	-	-
Anemone multifida[1]	-	-	-
Anemone patens[1]	-	-	-
Aralia nudicaulis[1]	-	-	-
Cornus canadensis[1]	-	-	-
Dracocephalum parviflorum[1]	-	-	-
Fragaria virginiana[1]	-	-	-
Geranium bicknellii[1]	-	-	-
Rubus pubescens[1]	-	-	-
Vicia americana[1]	-	-	-
Maianthemum canadense[1]	-	-	-
Potentilla tridentata[1]	-	-	-

[1] no analysis conducted.

Table 5.24. Mean percent root emergence of various plants for burial depths after 8 months of storage in large and small stockpiles.

Species	Control	Large Stockpile			Small Stockpile		p Values	
		0.05 m	2.0 m	6.0 m	0.05 m	3.0 m	One Way ANOVA	
							Large	Small
Arctostaphylos uva-ursi	85 (9.5)	5* (5.0)	0* (0.0)	0* (0.0)	0* (0.0)	0* (0.0)	0.003[2]	0.004[2]
Maianthemum canadense	100 (0.0)	25* (9.6)	10* (10.0)	5* (5.0)	15* (5.0)	10* (5.8)	<0.001[2]	<0.001[2]
Vaccinium myrtilloides	95 (5.0)	35* (17.1)	5* (5.0)	15* (9.6)	30* (17.3)	35* (12.6)	0.001[2]	0.001[2]

Data are mean and (standard error), n=4. In rows* denotes LFH treatments significantly different from the control. In rows different letters denote significant differences, where upper case letters denote a significant difference between stockpile size and lower case letters denote a significant difference between burial depths. Significant difference at $p \leq 0.05$. [2] rank transformed for data analysis.

Table 5.25. Mean percent root emergence of various plants for burial depths after 16 months of storage in large and small stockpiles.

Species	Control	Large Stockpile			Small Stockpile		p Values	
		0.05 m	2.0 m	6.0 m	0.05 m	3.0 m	One Way ANOVA	
							Large	Small
Arctostaphylos uva-ursi	85 (9.5)	0* (0.0)	0* (0.0)	0* (0.0)	0* (0.0)	0* (0.0)	<0.001[2]	<0.001[2]
Maianthemum canadense	100 (0.0)	0* (0.0)	0* (0.0)	0* (0.0)	0* (0.0)	0* (0.0)	<0.001[2]	<0.001[2]
Vaccinium myrtilloides	95 (5.0)	0* (0.0)	0* (0.0)	0* (0.0)	0* (0.0)	0* (0.0)	<0.001[2]	<0.001[2]

Data are mean and (standard error), n=4. In rows* denotes LFH treatments significantly different from the control. In rows different letters denote significant differences, where upper case letters denote a significant difference between stockpile size and lower case letters denote a significant difference between burial depths. Significant difference at $p \leq 0.05$. [2] rank transformed for data analysis.

Table 5.26. Spearman's correlation analysis data for grass and grass like species viability in large and small stockpiles.

Species	Large Stockpile						Small Stockpile					
	NH_4	Fe	CH_4	CO_2	O_2	C_2H_4	NH_4	Fe	CH_4	CO_2	O_2	C_2H_4
Agropyron	-0.089	0.004	-0.111	0.07	0.047	0.221	-0.516*	-0.02	0.479*	0.525*	-0.482*	0.463*
trachycaulum	(0.627)	(0.984)	(0.545)	(0.704)	(0.798)	(0.224)	(0.004)	(0.915)	(0.007)	(0.003)	(0.007)	(0.01)
Bromus ciliatus	0.022	0.113	-0.232	0.057	0.06	0.143	-0.747*	-0.252	0.215	0.546**	-0.541*	0.306
	(0.904)	(0.538)	(0.201)	(0.756)	(0.746)	(0.435)	(<0.001)	(0.178)	(0.255)	(0.002)	(0.002)	(0.1)
Carex anea	-0.395*	-0.208	-0.221	-0.333	.470*	0.043	-0.322	-0.155	0.044	-0.114	0.08	-0.112
	(0.025)	(0.254)	(0.224)	(0.063)	(0.007)	(0.815)	(0.083)	(0.415)	(0.819)	(0.548)	(0.675)	(0.557)
Elymus innovatus	-0.271	-0.214	-0.059	-0.14	0.199	0.073	-0.258	-0.071	-0.182	0.405*	-0.416*	0.138
	(0.134)	(0.241)	(0.749)	(0.444)	(0.275)	(0.691)	(0.169)	(0.709)	(0.337)	(0.026)	(0.022)	(0.469)
Oryzopsis pungens	-0.315	-0.286	-0.425*	-0.399*	0.487*	-0.08	-0.672*	-0.29	0.005	0.315	-0.332	0.199
	(0.079)	(0.112)	(0.015)	(0.024)	(0.005)	(0.663)	(<0.001)	(0.12)	(0.981)	(0.09)	(0.073)	(0.292)

Data are pearson correlation coefficient and (p value). * denotes significant difference at $p \leq 0.05$. NH_4 = available ammonium, Fe = available iron, CH_4 = methane, CO_2 = carbon dioxide, O_2 = oxygen, C_2H_4 = ethylene.

Table 5.27. Spearman's correlation analysis data for herbaceous species viability in large and small stockpiles.

Species	Large Stockpile						Small Stockpile					
	NH_4	Fe	CH_4	CO_2	O_2	C_2H_4	NH_4	Fe	CH_4	CO_2	O_2	C_2H_4
Anemone multifida	-0.238	-0.125	-0.316	-0.201	0.308	0.026	-0.550*	-0.069	0.111	0.114	-0.088	0.214
	(0.19)	(0.497)	(0.078)	(0.269)	(0.086)	(0.889)	(0.002)	(0.717)	(0.559)	(0.549)	(0.644)	(0.255)
Anemone patens	-0.325	-0.238	-0.318	-0.255	0.329	-0.046	-0.770*	-0.26	0.184	0.249	-0.207	0.243
	(0.07)	(0.19)	(0.077)	(0.159)	(0.066)	(0.805)	(<0.001)	(0.165)	(0.33)	(0.185)	(0.271)	(0.196)
Aralia nudicaulis	-0.125	-0.188	-0.452*	-0.315	0.387*	-0.229	-0.510*	-0.251	-0.008	0.085	-0.052	0.022
	(0.494)	(0.302)	(0.009)	(0.079)	(0.029)	(0.207)	(0.004)	(0.181)	(0.966)	(0.657)	(0.784)	(0.91)
Cornus canadensis	-0.418*	-0.225	-0.31	-0.301	0.427*	0.068	-0.653*	-0.323	0.002	0.367*	-0.348	0.252
	(0.017)	(0.215)	(0.084)	(0.095)	(0.015)	(0.713)	(<0.001)	(0.081)	(0.991)	(0.046)	(0.06)	(0.179)
Dracocephalum	-0.387*	-0.255	-0.253	-0.423*	0.374*	-0.356*	-0.062	-0.2	-0.071	0.109	-0.065	0.001
parviflorum	(0.029)	(0.159)	(0.162)	(0.016)	(0.035)	(0.045)	(0.746)	(0.289)	(0.71)	(0.565)	(0.731)	(0.996)
Fragaria	-0.350*	-0.179	-0.332	-0.292	0.380*	-0.083	-0.730*	-.367*	0.066	0.134	-0.121	0.106
virginiana	(0.05)	(0.327)	(0.063)	(0.105)	(0.032)	(0.652)	(<0.001)	(0.046)	(0.731)	(0.481)	(0.525)	(0.576)
Geranium	-0.056	-0.345	0.031	0.032	0.021	0.296	-0.042	-0.098	-0.115	0.085	-0.09	-0.137
bicknellii	(0.763)	(0.053)	(0.868)	(0.863)	(0.911)	(0.1)	(0.824)	(0.606)	(0.545)	(0.657)	(0.638)	(0.471)
Rubus pubescens	-0.437*	-0.444*	-0.558*	-0.561**	0.621*	-0.203	-0.639*	-0.343	0.022	-0.173	0.218	-0.033
	(0.012)	(0.011)	(0.001)	(0.001)	(<0.001)	(0.264)	(<0.001)	(0.063)	(0.908)	(0.361)	(0.248)	(0.864)
Potentilla	-0.374*	-0.191	-0.442*	-0.338	0.441*	-0.088	-0.738*	-0.268	0.045	0.183	-0.132	0.19
tridentata	(0.035)	(0.295)	(0.011)	(0.059)	(0.012)	(0.63)	(<0.001)	(0.152)	(0.815)	(0.332)	(0.487)	(0.315)
Maianthemum	-0.209	-0.284	-0.422*	-0.359*	0.447*	-0.133	-0.626*	-0.284	0.071	0.135	-0.082	0.285
canadense	(0.25)	(0.116)	(0.016)	(0.044)	(0.01)	(0.469)	(<0.001)	(0.129)	(0.708)	(0.477)	(0.665)	(0.128)
Vicia americana	0.023	0.214	0.153	0.136	-0.034	0.246	-0.042	-0.132	-0.257	0.263	-0.299	-0.166
	(0.902)	(0.239)	(0.402)	(0.458)	(0.852)	(0.174)	(0.825)	(0.486)	(0.17)	(0.161)	(0.108)	(0.381)

Data are pearson correlation coefficient and (p value). * denotes significant difference at $p \leq 0.05$. NH_4 = available ammonium, Fe = available iron, CH_4 = methane, CO_2 = carbon dioxide, O_2 = oxygen, C_2H_4 = ethylene.

Table 5.28. Spearman's correlation analysis data for woody species viability in large and small stockpiles.

Species	Large Stockpile						Small Stockpile					
	NH_4	Fe	CH_4	CO_2	O_2	C_2H_4	NH_4	Fe	CH_4	CO_2	O_2	C_2H_4
Alnus crispa	-0.086	-0.302	-0.25	-0.132	-0.214	0.261	-0.631*	-0.178	0.226	0.098	-0.046	0.35
	(0.64)	(0.093)	(0.167)	(0.472)	(0.241)	(0.148)	(<0.001)	(0.348)	(0.23)	(0.606)	(0.808)	(0.058)
Arctostaphylos	-0.149	-0.102	-0.139	0.008	0.034	0.153	-0.619*	-0.092	0.256	0.415*	-0.374*	0.325
uva-ursi	(0.414)	(0.577)	(0.447)	(0.964)	(0.854)	(0.404)	(<0.001)	(0.63)	(0.172)	(0.023)	(0.042)	(0.08)
Prunus	-0.373*	-0.343	-0.383*	-0.462*	-0.522*	0.606*	-0.614*	-0.377*	-0.065	0.06	0.016	0.069
pensylvanica	(0.036)	(0.054)	(0.03)	(0.008)	(0.002)	(<0.001)	(<0.001)	(0.04)	(0.734)	(0.752)	(0.934)	(0.717)
Ribes	-0.184	-0.231	-0.16	-0.077	-0.096	0.249	-0.817*	-0.215	0.119	0.366*	-0.307	0.228
hudsonianum	(0.313)	(0.203)	(0.383)	(0.676)	(0.601)	(0.169)	(<0.001)	(0.253)	(0.532)	(0.047)	(0.099)	(0.225)
Rosa acicularis	-0.158	-0.125	-0.038	-0.136	-0.027	0.179	-0.749*	-0.235	0.216	0.415*	-0.345	0.287
	(0.388)	(0.497)	(0.836)	(0.458)	(0.882)	(0.327)	(<0.001)	(0.211)	(0.251)	(0.023)	(0.062)	(0.124)
Rubus idaeus	-0.427*	-0.309	-0.386*	-0.510*	-0.359*	0.466*	-0.505*	-0.292	0.055	0.1	-0.072	0.161
	(0.015)	(0.085)	(0.029)	(0.003)	(0.043)	(0.007)	(0.004)	(0.117)	(0.772)	(0.601)	(0.707)	(0.395)
Shepherdia	-0.333	-0.492*	-0.364*	-0.465*	-0.595*	0.618*	-0.707*	-0.318	-0.071	0.014	0.073	0.033
canadensis	(0.063)	(0.004)	(0.04)	(0.007)	(<0.001)	(<0.001)	(<0.001)	(0.086)	(0.709)	(0.943)	(0.701)	(0.861)
Vaccinium	-0.381*	-0.366*	-0.374*	-0.511*	-0.491*	0.574*	-0.575*	-.433*	0.011	-0.119	0.2	-0.013
myrtilloides	(0.031)	(0.039)	(0.035)	(0.003)	(0.004)	(0.001)	(0.001)	(0.017)	(0.956)	(0.531)	(0.289)	(0.945)
Vaccinium vitis-	-0.295	-0.273	-0.328	-0.450*	-0.431*	0.541*	-0.757*	-0.2	0.16	0.216	-0.172	0.268
idea	(0.101)	(0.131)	(0.067)	(0.01)	(0.014)	(0.001)	(<0.001)	(0.29)	(0.399)	(0.251)	(0.362)	(0.152)
Virburnum edule	-0.339	-0.264	-0.369*	-0.372*	-0.235	0.423*	-0.786*	-0.289	0.206	0.283	-0.261	0.194
	(0.058)	(0.144)	(0.038)	(0.036)	(0.196)	(0.016)	(<0.001)	(0.122)	(0.275)	(0.129)	(0.163)	(0.303)
Pinus banksiana	-0.28	-0.342	-0.362*	-0.362*	-0.502*	0.556*	-0.524	-0.202	-0.095	-0.168	0.2181	-0.057
	(0.12)	(0.056)	(0.042)	(0.042)	(0.003)	(0.001)	(0.003)	(0.285)	(0.617)	(0.374)	(0.247)	(0.766)

Data are pearson correlation coefficient and (p value). * denotes significant difference at $p \leq 0.05$. NH_4 = available ammonium, Fe = available iron, CH_4 = methane, CO_2 = carbon dioxide, O_2 = oxygen, C_2H_4 = ethylene.

CHAPTER VI
BURIAL DEPTH, SOIL TEXTURE AND SOIL WATER EFFECTS ON EMERGENCE OF *VACCINIUM MYRTILLOIDES, VIRBURNUM EDULE* AND *MAIANTHEMUM CANADENSE* FROM ROOT CUTTINGS

6.1 INTRODUCTION

Boreal forest topsoil, or LFH, provides an abundant source of seeds and vegetative propagules for a diversity of native species, the majority of which are not commercially available for large scale revegetation. Vegetative propagules can account for a high percentage of emergents from direct placed LFH; however, species might not emerge if vegetative propagules are buried deep or in dry soil. With deep placed LFH, vegetative propagules could be buried too deeply for emergence and with shallow placed LFH they could dry out. Although propagule banks have been intensively studied, particularly the seed component, the role of vegetative propagules has had little attention until recently (Klimešová and Klimeš 2006). Seedling emergence is controlled by several factors, including temperature, water potential, burial depth and soil texture (Prostko et al. 1997).

Most research on effects of burial depth on roots has been on weed species. Vegetative propagule abundance naturally decreases with increasing soil depth; however, applying LFH or other topsoils results in variable propagule distribution. After donor soils are applied to reclamation areas, deeply buried propagules might not emerge (Grant et al. 1996) due to insufficient energy reserves (Batson 1998). Klimeš et al. (1993) found carbohydrate reserves limited emergence of *Rumex alpinus* L. (alpine dock) rhizomes at 20 cm and no plants emerged from 30 cm. Increased burial depth of *Achillea millefolium* L. (common yarrow) rhizomes significantly decreased shoot emergence and dry weight of aerial shoots and new rhizomes (Bourdôt 1984).

Most studies assessing donor soils as a seed source concluded shallow and deep applications of topsoil resulted in similar plant establishment (Rokich et al. 2000, Holmes et al. 2001). If soil application is shallow, vegetative propagules can

emerge but available water and nutrients could limit establishment. Few studies have determined effects of soil texture and soil water. Emergents from roots and rhizomes might not materialize if soil is too dry or too wet. Shen et al. (2005) determined no shoots emerged from rhizomes of *Alternanthera philoxcroides* (Matt.) Griseb ALRPH (alligator weed) when gravimetric soil water was at 5 or 60 % and optimum emergence occurred at 30 % soil water. Bourdôt (1984) determined there was no difference in *Achillea millefolium* emergence from rhizomes buried 2 to 30 cm in silt loam or fine sandy loam textured soils.

Understanding effects of burial depth, soil texture and soil water on emergence from vegetative propagules for a range of native boreal species will help in design of placement depths during reclamation for a range of soil conditions and landscape positions. The objective of this research was to determine the effects of burial depth, soil texture and soil water on emergence of *Virburnum edule* (Michx.) Raf (low bush cranberry), *Vaccinium myrtilloides* Michx. (blueberry) and *Maianthemum canadense* (Desf) (wild lily of the valley) from root cuttings.

6.2 MATERIALS AND METHODS

6.2.1 Root Collection, Experimental Design and Green House Procedures

Roots from three boreal plant species, *Virburnum edule*, *Vaccinium myrtilloides* and *Maianthemum canadense*, were collected from undisturbed forests on the Syncrude Canada Ltd. Aurora North mine (latitude 57^{o} 21’ N, longitude 111^{o} 31’ W) in May 2009. The collection site was located in the central mixed wood subregion of the boreal natural region (Natural Regions Committee 2006). Climate is cool temperate with short, cool summers and long, cold winters (Strong and Leggat 1992). Mean annual temperature is 0.3 ºC. The 1944 to 2007 long term average annual precipitation was 471.2 mm, with approximately 322.7 mm of rain and 148.5 cm of snow (Sycnrude Canada 2008).

Plants were extracted from the soil with a shovel and attached roots were pulled out of the ground. Foliage was cut off at the crown. Roots were stored in damp

paper towel in sealable plastic bags, transported to the University of Alberta and kept at 4°C under controlled refrigeration for 7 days (cold stratification).

A 3 x 3 x 2 factorial, completely randomized design was used to determine the effects of burial depth (2, 5, 10 cm), soil water content (dry, damp, wet) and soil texture (sand, clay loam) on emergence from roots. The growing medium was forest topsoil collected from below 1 m in two large stockpiles because it has a low abundance of viable propagules. Recent research suggests there are few viable propagules below 1 m of large stockpiles (Chapter 5). Sandy soil was taken from the Syncrude Canada Ltd. Aurora North mine; sand and clay loam textured soil were procured from the Canadian Natural Resources Ltd. Horizon mine (latitude 57^{o} 21' N, longitude 111^{o} 48 W).

Roots from each species were cut into 7.5 cm segments prior to burial. Five root segments for each species and each burial depth were placed horizontally in a single pot for a total of 5 roots per pot. Burial depths were obtained by placing the specific volume of soil into pots prior to placing roots, then adding surface soil to each pot to cover the placed roots. Each 1200 cm^3 pot was filled with 1000 cm^3 of soil. Each treatment combination was replicated 4 times, 72 pots per species. A total of 216 pots were randomly placed in a University of Alberta greenhouse.

To determine a watering regime that would result in dry, damp and wet soil, porosity and matric potentials for each soil texture were determined (Table 6.1). Three samples from bulk soil from each stockpile were used to determine bulk density and porosity was calculated using the equation: Ø = 1 - (bulk density/2.65) (Carter 1993). Water retention of each soil was determined using the pressure plate method for matric potentials of -15 bars and -0.3 bars (Hillel 1980). To maintain dry, damp and wet water contents for 1000 cm^3 of soil, pots with drainage holes containing coarse texture soil were watered every 2 to 3 days with 50, 100 and 200 ml of water, respectively; clay loam textured soils were watered with the same amount of water every 4 to 6 days. Pots were randomly shuffled during each watering period. Plant shoot emergence was monitored at weekly intervals for a total of 8 weeks.

6.2.2 Statistical Analyses

Inferential statistics were planned and the experimental design was to be treated as a three way analysis of variance (ANOVA) with fixed effects. However, could the residuals did not meet assumptions of normality or homogeneity of variances using the Shapiro-Wilk test and homogeneity of variances with Levene's test in SPSS 18.0 and transformations were not effective. Therefore, performing traditional inferential statistics, such as parametric and non-parametric ANOVA, were inappropriate. Attempts to analyze textures separately in a two way ANOVA did not resolve this issue. Thus, means and standard errors are presented.

6.3 RESULTS AND DISCUSSION

Of the three factors studied (texture, water content, burial depth), burial depth had the greatest effect on emergence of *Vaccinium myrtilloides* and *Maianthemum canadense*; soil water had the greatest effect for *Viburnum edule* (Table 6.2). Burial depth was the only factor that affected *Maianthemum canadense* emergence, which declined for each increased increment of burial depth.

Reduced emergence from roots of *Maianthemum canadense*, *Viburnum edule* and *Vaccinium myrtilloides* with deep (10 cm) burial is similar to other research. Emerging *Mentha arvensis*, L. (field mint) shoots significantly declined with increasing burial depth; however, number of shoots from roots 2.5 and 5.0 cm deep were similar (Ivany 1997). Number of *Potamogeton gramineus* L. (variable leaf pondweed) ramets from rhizomes was significantly reduced when buried deeper than 5 cm (Spencer and Ksander 1990). Increasing burial depth of *Achillea millefolium L*. (common yarrow) rhizomes reduced survival and emergence; however, effects were less detrimental with longer rhizomes (Bourdôt 1984). Mueller (1975) buried rhizomes from 8 prairie species (*Andropogon furcatus* Muhl. (big bluestem), *Artemisia gnaphalodes* Michx. (prairie sage), *Aster multiflorus* Ait. (many flowered aster), *Agropyron smithii* Rydb. (western wheat grass), *Bouteloua gracillis* H.B.K (blue grama grass), *Calamovilfa longifolia*

(Hook) Scribn.(sand reed grass), *Solidago glaberrima* Martens (smooth goldenrod) and *Sparina pectinata* Link (slough grass)) at various depths; emergence declined substantially when rhizomes were buried from 7.62 to 15.24 cm except for *Aster multiflorus, Calamovilfa longifolia* and *Solidago glabberima,* which did not emerge from 25.4 cm burial depths. Effect of rhizome length on emergence at different burial depths requires further study for our species.

Besides burial depth, resistance to desiccation is crucial in establishment from roots. Roots uncovered on the soil surface are prone to lethal water loss, and physiological properties determine how long a root piece can survive drying conditions (Weber 2011). Effect of soil water was species specific with *Maianthemum canadense* favouring dry sandy soils. *Viburnum edule* was the least tolerant to dry soil conditions and emerged best when soils were damp. Soil water had an effect on *Viburnum edule* emergence when buried at 2 and 5 cm; however, few shoots emerged at 10 cm burial depth under all three hydrologic regimes. Few emergents occurred in wet soil for each burial depth and in dry soil when buried at 2 and 10 cm. Dry soil conditions in this experiment likely caused roots of some species to desiccate when buried at 2 cm, but sufficient water was available at 5 cm. Under wet conditions few shoots emerged from depths of 5 and 10 cm. After the first 2 weeks soils were typically saturated below 2 cm with the wet regime and few shoots would have emerged under these poorly aerated conditions.

Soil texture influence on *Vaccinium myrtilloides* appeared interactive with soil water and burial depth. In sandy soils, emergence decreased with increasing burial depth under damp and wet conditions. Very few emergents were found in wet soils and none at 10 cm. Emergence was greatest in damp, sandy soil when roots were buried at 2 cm. In clay loam soil, emergence decreased with increasing depth; however, no shoots emerged in wet soils. *Vaccinium myrtilloides*, like *Maianthemum canadense,* is typically found in sandy soils; therefore, it is not surprising their greatest shoot emergence was in sandy soils. The subtle differences in *Viburnum edule* shoot emergence between the two soil textures at 2 cm burial depth is not considered of significance given the high variability found in the clay loam soil.

Deep placement of donor soils on land to be reclaimed could prevent plant emergence from roots. Larger fragments of deeply buried roots might have sufficient carbohydrate reserves to establish from greater depths (Weber 2011), however, this is still undetermined for many boreal species. A sufficient amount of soil water would be required for most plants to emerge from roots if donor soils were shallow placed; if dry conditions persisted roots would desicate. Drought tolerant plant species like *Maianthemum canadense* could successfully establish from shallow buried rhizomes when soil conditions are dry, but rhizomes from non drought tolerant species would likely desiccate in the absence of rainfall soon after soil placement. An intermediate application depth of donor soils is likely the most effective way of redistributing donor soils to maximize emergence of plants from roots; however, a depth that is intermediate cannot be defined until a further range of deep burial depths is studied with varying lengths of roots.

6.4 CONCLUSIONS

Effects of texture, water content and burial depth on shoot emergence from roots of *Maianthemum canadense*, *Viburnum edule* and *Vaccinium myrtilloides* was species specific. Texture had the most influence on *Vaccinium myrtilloides*, with shoot emergence greatest on sandy soils. Damp soils resulted in greatest shoot emergence for all species at most depths above 10 cm. Generally shoot emergence decreased with increasing root burial depth; however, under dry conditions both *Viburnum edule* and *Vaccinium myrtilloides* shoot emergence was greatest at 5 cm. Roots buried at 10 cm resulted in very few emergents for all three species and few roots buried greater than 2 cm emerged under wet soil conditions.

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Table 6.1. Mean bulk density, porosity and gravimetric water content at -0.3 and -15 bar from coarse and fine textured soil used in experiment.

Soil Texture	Bulk Density (g/cm^3)	Porosity	Water Content	
			-0.3 bar	-15 bar
Coarse	1.04	0.61	6.12	2.32
	(0.01)	(0.01)	(0.19)	(0.17)
Fine	0.82	0.69	20.89	7.22
	(0.01)	(0.01)	(0.21)	(0.06)

Numbers are means and (standard errors). n=3.

Table 6.2. Mean number of emergents of *Viburnum edule*, *Vaccinium myrtilloides* and *Maianthemum canadense* under various texture, hydrologic and burial depth conditions.

Burial Depth (cm)	Coarse Textured			Fine Textured		
	Dry	Damp	Wet	Dry	Damp	Wet
Viburnum edule						
2	0.0	4.0	1.0	0.3	3.5	0.0
	(0.0)	(2.0)	(0.5)	(0.1)	(1.8)	(0.0)
5	1.5	2.3	0.0	1.8	1.5	0.0
	(0.8)	(1.1)	(0.0)	(0.9)	(0.8)	(0.0)
10	0.3	0.3	0.0	0.0	0.8	0.0
	(0.1)	(0.1)	(0.0)	(0.0)	(0.4)	(0.0)
Vaccinium myrtilloides						
2	1.0	15.0	0.5	2.8	4.0	0.0
	(1.0)	(3.2)	(0.3)	(2.8)	(1.7)	(0.0)
5	4.0	2.3	0.0	1.5	0.8	0.0
	(1.7)	(0.9)	(0.0)	(1.0)	(0.5)	(0.0)
10	0.0	0.0	0.0	0.8	0.3	0.0
	(0.0)	(0.0)	(0.0)	(0.5)	(0.3)	(0.0)
Maianthemum canadense						
2	4.0	4.5	5.3	1.3	3.8	3.5
	(0.0)	(0.6)	(1.1)	(1.3)	(0.5)	(1.0)
5	1.8	3.5	1.5	2.3	2.5	1.8
	(1.0)	(0.5)	(0.9)	(0.6)	(0.9)	(1.0)
10	0.5	0.0	0.0	0.5	0.0	0.0
	(0.5)	(0.0)	(0.0)	(0.5)	(0.0)	(0.0)

Numbers are means and (standard errors). n=4.

CHAPTER VII
EFFECT OF PLANT DERIVED SMOKE WATER AND POTASSIUM NITRATE ON GERMINATION OF BOREAL FOREST PLANTS

7.1 INTRODUCTION

Biotic responses to disturbance are a key factor in understanding ecosystem dynamics (Chapin et al. 1996, Gibson et al. 2000) and developing tools for management and reclamation. Species have developed evolutionary strategies to respond to major disturbances in an ecosystem. Disturbances such as fire, tree throw and insect outbreaks occur frequently in the boreal forest (Larsen 1980, Suffling et al. 1988, Bonan and Shugart 1989, Payette 1992), creating open spaces and releasing elements and compounds (Connell and Slatyer 1977, Schaetzl et al. 1989). Released elements or compounds can create germination cues for plants; these cues and the mechanisms involved vary among species (Sousa 1984).

Seed dormancy and germination is stimulated or released by diverse exogenous and endogenous factors such as light, chilling, warm stratification, temperature fluctuation, gibberellins, nitrogen containing compounds and other hormones (Keeley and Fotheringham 1998, Baskin and Baskin 2001, Finch-Savage and Leubner-Metzger 2006). Smoke induced seed germination has been reported to enhance germination in regions subject to frequent wildfires, such as, South Africa, Western and Southern Australia (Dixon et al. 1995, Merritt et al. 2006), California (Keeley and Fotheringham 1998) and the central Mediterranean (Perez-Fernandez and Rodriguez-Echeverria 2003). Most germination studies in boreal forest have only used heat, fluctuating temperature regimes and cold stratification (Baskin and Baskin 2001). Few studies have assessed the effects of smoke on germination of boreal forest plants (Tsuyuzaki and Miyoshi 2009). Plant derived smoke waterinduced germination has not been reported for the boreal forest.

Natural disturbances that created gaps in the forest canopy increase soil temperatures, which increase mineralization rates, resulting in increased available nitrogen. Forest fires often increase nitrogen availability through soil heating and

additions from ash; however, stimulatory effects are dependent on fire severity (Bonan and Shugart 1989). Stimulatory effects of nitrate on seed germination are well known (Toole et al. 1956); however, effects on boreal taxa are limited to a few species. Calcium nitrate applied at 336 kg ha^{-1} to mature *Abies balsamea* (L.) Mill. (balsam fir) and *Picea mariana* (Mill.) BSP (black spruce) stands, increased *Rubus idaeus* L. (red raspberry) emergence by 75 plants 25 m^{-2} versus no fertilizer (Jobidon 1993). Auchmoody (1979) assessed response of *Prunus pensylvanica* L. (pin cherry) emergence in a 60 year old Allegheny hard wood forest using several sources of nitrogen fertilizers; no fertilizer resulted in no emergence and after the second growing season nitrogen fertilizer plots averaged 272,000 to 675,000 seedlings ha^{-1}. Increased nitrification often occurs in forests following canopy or soil disturbance; therefore, nitrate concentration could indicate reduced competition from other plants (Hintikka 1987).

Stimulated germination from plant derived smoke was first reported by De Lange and Boucher (1990). They found smoke acted as a cue for breaking dormancy of threatened fynbos species, *Audouinia capitata* (L.) Brongn (false heath). Over 170 native Australian species from 37 families showed enhanced germination from smoke (Roche et al. 1997, Bell 1999). Smoke is effective on species from a wide range of families, varying in ecology, reproductive strategy, seed size and morphology (Dixon et al. 1995). Stimulatory effects of smoke are not limited to species in fire prone environments. Germination was stimulated in *Lactuca* L. (lettuce) (Drewes et al. 1995), (*Apium graveolens* L. (celery) (Thomas and Van Staden 1995) and several biotypes of *Avena fauta* L. (wild oat), including one from Canada (Adkins and Peters 2001). Smoke can be applied to seeds directly or on seed banks in various forms such as concentrated smoke water and cool aerosol smoke. Smoke water is most easily handled and applied to large projects.

Many species, particularly native species, have very low germination rates, making reclamation difficult and slow. Germination can increase by simulating natural disturbances to which species would respond. From forest management and reclamation perspectives, understanding germination response to nitrogen is valuable in controlling colonizing vegetation that competes with trees

(Auchmoody 1979). Determining germination response through nitrogen additions from a wide range of species would be beneficial in promoting vegetation establishment on denuded landscapes. Determining if nitrogen and/or smoke enhances germination is of interest for potential commercial applications.

The objectives of this research were to determine if seed germination is enhanced by potassium nitrate or plant derived smoke water for a range of common boreal plants using non stratified and cold stratified seeds. The research will have direct application to revegetation of boreal forest landscapes.

7.2 MATERIALS AND METHODS

7.2.1 Seed Collection, Processing and Viability

Seeds of 18 species were hand collected from logged and undisturbed forests in the Athabasca Oil Sands Region in Northeastern, Alberta. Collection sites were located in the central mixed wood subregion of the boreal natural region. Climate was cool temperate with short, cool summers and long, cold winters (Strong and Leggat 1992). Mean annual temperature was 0.3 ºC. The 1944 to 2007 long term average annual precipitation was 471.2 mm, with approximately 322.7 mm of rain and 148.5 cm of snow (Syncrude Canda 2008).

For some species, multiple populations were collected (Table 7.1). All seeds were collected when ripe between July and September 2006. All species were perennials except the annual *Chenopodium capitatum* (L.) Aschers (strawberry blite). Seeds were air dried at room temperature aided by a fan for 2 weeks before dark storage in sealed mason jars at room temperature. Berries of *Ribes hudsonianum* Richards. (wild black currant), *Vaccinium myrtilloides* Michx (blueberry) and *Fragaria virginiana* Duchesne (wild strawberry) were macerated in a blender, then screened and cleaned with tap water to prevent loss in viability from fungus. Fleshy outer seed coats of single seeded berries were hand removed for *Cornus canadensis* L. (bunchberry), *Maianthemum canadense* Desf. (wild lily of the valley), *Prunus pensylvanica* (L.f) (pin cherry) and *Shepherdia canadensis*

(L.) Nutt. (canada buffalo berry). Macerated seeds and seeds with fleshly outer coats were air dried with the aid of a fan for 2 weeks after processing. Seeds were removed from sealed mason jars when treatments were applied.

Prior to treatment, 4 replicates of 25 seeds of each species were tested for viability using 1 % tetrazolium solution. Tetrazolium solutions, seed treatments, cutting methods and staining evaluations were done according to the Association of Official Seed Analysts (Peters 2000) and the International Seed Testing Association (2003). Mean viability for all species is presented in Table 7.1.

Seeds were cold stratified and non stratified. For cold stratification seeds were stored on damp paper towel in a refrigerator at 2 to 4 °C for 6 weeks prior to beginning the experiment, which was conducted over 2 months.

7.2.2 Treatment Solutions Preparation

Treatments were solutions of smoke water, potassium nitrate, smoke water + potassium nitrate and distilled water (control). Smoke water was produced by bubbling smoke from a 200 L steel combustion drum through 20 L of distilled water for 120 min. Forty five kilograms of cut hay procured from Rabbit Lake, Saskatchewan, composed of mostly *Medicago sativa* L. (alfalfa), *Phleum pratense* L. (timothy) and *Bromus biebersteinii* Roem. & Schult. (meadow brome) was used as fuel. Extensive studies have shown the nature of combustion materials (wood shavings, straw, green leaf, pure cellulose) does not alter effectiveness of the smoke reaction in native seeds (Brown and Van Staden 1997). Five batches of smoke water were made and one batch was used for each replicate.

Data on optimal dilutions of smoke water for germinating boreal species are not available, therefore an intermediate ratio was selected. For treatment application, smoke water was diluted with distilled water at a 1:20 ratio. Solutions of potassium nitrate were made by dissolving 2 g of potassium nitrate in 1000 ml of distilled water. Insufficient data are available on optimal rates of potassium nitrate for germinating boreal species, thus concentrations of potassium nitrate were applied at 0.2 % solution. Solutions of 0.1 to 0.2 % potassium nitrate are common

in routine germination testing and are recommended by the Association of Official Seed Analysts and the Interna-tional Seed Testing Association for germination tests of many species (Copeland and McDonald 1995). Smoke water + potassium nitrate solutions were prepared by adding 2 g of potassium nitrate in 1000 ml of 1:20 smoke water solution. Control solutions were distilled water.

7.2.3 Germination Experiment

Each treatment was replicated 5 times, with each replicate having 25 seeds of a single species. Seeds were placed on dry Anchor steel blue seed germination blotter paper in sealable, clear, 10 x 10 cm plastic germination containers. To each container with seed, 25 ml of treatment solution was added, then air dried by removing container lids when they were placed in the growth chamber for 12 hr. Containers were randomly placed in the growth chamber and randomly moved to different locations every week. Seeds were kept damp by watering with distilled water 1 to 2 times a week and containers were sealed with lids after each watering. Temperature and light conditions in the growth chamber were selected to mimic growing conditions at Fort McMurray at 28 °C in light for 16 hours and 15 °C in dark for 9 hours. Germination was determined on a weekly basis. A seed was considered germinated when the first radical emerged and a root was considered emerged when the first shoot emerged.

7.2.4 Statistical Analyses

Data were analyzed using a two way fixed effects analysis of variance (ANOVA (Zar 1999). Significant main effects for solution treatments were further analyzed using least squares difference (LSD) post hoc test (Carmer and Swanson 1973). Similarly, significant interaction effects in two way ANOVA were analysed by comparing all treatments using one way ANOVA, if main effects were significant differences among treatments were further analyzed using LSD. Very few seeds (< 1 to 2 per replicate) of *Maianthemum canadense*, *Rubus pubescens* and *Prunus pensylvanica* germinated, therefore, no values are presented. Significant

interactions were analyzed using one way ANOVA and interaction plots. Residuals from raw data were tested for assumptions of normality based on the Shapiro-Wilk test and assumption of homogeneity of variances based on Levene's test. Rank transformation was used when variances of raw data were heterogeneous. Data analyses were conducted using SPSS 18.0. A p value of $\leq$0.05 was used to determine significant effects.

7.3 RESULTS AND DISCUSSION

7.3.1 Stratification

Cold stratification had a significant effect on germination of 9 species; however, it was not always independent of treatment solutions (Figures 7.1 to 7.5). Cold stratification significantly increased germination of *Bromus ciliatus*, *Cornus canadensis* and *Fragaria virginiana* but treatment solutions did not (Table 7.2, Figure 7.1). Cold stratification significantly decreased *Vaccinium myrtilloides* germination and significantly increased germination of *Shepherdia canadensis* (Figure 7.2). Data for cold stratified *Agropyron trachycaulum*, *Chenopodium capitatum* and *Vicia americana* were not available as most viable seeds germinated during cold stratification; non stratified seeds were not significantly affected by treatment solutions (Figure 7.3).

Most boreal shrub species have seeds with physiological dormancy and most herbaceous seeds have either physiological or morpho-physiological dormancy (Baskin and Baskin 2001). Seeds with physiological dormancy typically require cold stratification for germination. Seeds with non-deep physiological dormancy may germinate if exposed to short periods of warm or cold stratification and gibberellic acid (Baskin and Baskin 2004). Seeds with intermediate physiological dormancy require 2 to 3 months of cold stratification to break dormancy and gibberellic acid promotes germination in some species. Seeds with deep physiological dormancy require 3 to 4 months of cold stratification, but gibberellic acid does not promote germination.

This experiment was not set up to determine type of seed dormancy for each species; however, 9 species displayed some physiological dormancy as germination increased when seeds were exposed to cold stratification. *Cornus canadensis*, *Shepherdia canadensis* and *Schizachne purpurascens* displayed the strongest evidence for physiological dormancy as none or few seeds germinated under control conditions when not cold stratified.

Other studies have shown chilling seeds increased germination of *Shepherdia canadensis*, *Oryzopsis pungens*, *Ribes* spp., *Fragaria virginiana*, *Cornus canadensis* and *Potentilla tridentata* (Nichols 1934, McLean 1967, Whittle et al. 1997). Lack of germination for *Prunus pensylvanica*, *Rubus pubescens* and *Maianthemum canadensis* indicates seeds are still dormant. Seeds of *Prunus pensylvanica* and *Maianthemum canadensis* have morpho-physiological dormancy (Young and Young 1992, Basking and Baskin 2001) and *Rubus* spp. seeds have deep dormancy (Jennings 1988). It is not surprising none of these seeds germinated as warm stratification was not imposed prior to cold stratification or a prolonged (> 2 mo) cold stratification was not imposed.

Physical dormancy has been reported in species from the *Fabaceae* family, however, scarification of *Vicia americana* might not improve germination (McLean 1967). Seed germination could not be tested on cold stratified seeds of *Vicia americana*, because most had germinated while in cold stratification. This suggests *Vicia americana* does not need scarification to break dormancy.

Other species that germinated under cold conditions included *Agropyron trachycaulum* and *Chenpodium capitatum*. Both germinated with non stratified seed under control conditions suggesting seeds are not dormant. Stratification reduced germination of *Vaccinium myrtilloides* and *Anemone patens*. Stratification likely caused these species to enter a secondary dormancy. Seeds of many blueberries (*Vaccinium* spp.) are not dormant and require no treatment for germination (Young and Young 1992). Sorensen and Holden (1974) showed germination of *Anemone patens* from South Dakota decreased slightly after 1 mo of cold stratification and increased slightly after 2 mo of cold stratification. A

longer time period in the growth chamber would have been required for some species, such as *Ribes hudsonianum*, to reach maximum potential germination. Decay by fungus in the germination trays reduced germination for some species, such as *Vicia americana*, *Shepherdia canadensis* and *Anemone patens*.

7.3.2 Effect of Smoke Water

Smoke water enhanced germination of 9 native boreal forest species (Table 7.3). Germination of *Vacciunium myrtilloides* was significantly greater with smoke water and significantly lowest with potassium nitrate and with smoke water + potassium nitrate regardless of stratification treatment (Figure 7.2). *Potentilla tridentata* germination was greatest in the control and with smoke water; although not statistically significant, germination was greater with smoke water than in the control (Figure 7.2). Germination of *Shepherdia canadensis* was significantly greater with potassium nitrate and smoke water + potassium nitrate for cold stratified and non stratified seeds. To our knowledge the species in this study that responded positively to smoke water are the first to be reported.

Isolation of a new compound from smoke that stimulates seed germination has been characterized as butenolide 3-methyl-2H-furo[2,3-c]-pyran-2-one, isolated from plant-derived smoke (Van Staden et al. 2004), burned cellulose (Flematti et al. 2004) and products formed by heating carbohydrates and amino acids (Light et al. 2005). Smoke influences how seeds respond to light and gibberellic acid, and appears to affect endogenous gibberellic acid synthesis and abscisic acid content (Van Staden et al. 2000). This smoke induced promotion of germination is similar to that achieved by treating seeds with gibberellic acid 3 (Van Staden et al. 1995).

Response to smoke was dependent on species, type of stratification and presence of potassium nitrate (Table 7.3). Data are limited for comparison of most species in this study. Brown (1993) found plant derived smoke extract significantly increased germination of a species from the *Ericaceae* family (*Erica glomiflora* (heath). In African fynbos, germination of 150 of 301 species examined was improved by smoke, including those in *Ericaceae* (Brown et al. 2003). We

examined one *Ericaceae* species (*Vaccinium myrtilloides*) and seed germination increased with smoke water. It is well known that gibberellic acid promotes germination of seeds with physiological dormancy and can substitute for cold stratification for many seeds (Finch-Savage and Leubner-Metzger 2006). It is likely that the species with a positive response to smoke in this study would also respond positively to gibberellic acid 3. Germination of *Vaccinium corymbosum* L. (high bush blueberry) can be enhanced by gibberellic acid 3 (Dweikat and Lyrene 1988). Species (*Ribes hudsonianum* and *Shepherdia canadensis*) with improved seed germination from smoke x potassium nitrate, but not smoke water, appeared to be responding to potassium nitrate as response was more positive for potassium nitrate. However, there may be interactions as *Elymus innovatus* and *Fragaria virginiana* had similar germination when either of these treatments were applied, but germination was greater when smoke + potassium nitrate was used.

The negative effect of smoke water on *Schizachne purpurascens*, *Oryzopsis pungens*, *Ribes hudsonianum* and *Anemone multifida* occurred only when seeds were cold stratified. Smoke water enhanced germination of *Schizachne purpacscens*, *Oryzopsis pungens* and *Anemone multifida* in non stratified seeds. Highly concentrated aqueous smoke extracts inhibit germination but are not toxic to seeds (Brown and Van Staden 1997). Exposure longer than 10 min can have negative effects in some species of California chaparral (Keeley and Fotheringham 1998). Clarke et al. (2000) reported smoke suppressed germination of 6 species from New South Wales, Australia. Gómez-González et al. (2008) hypothesized smoke induced dormancy of forbs in grass communities delayed germination in competitive post fire environments (Clarke et al. 2000). In our study smoke induced dormancy of several species but only after seeds were stratified. Delayed germination of some herbaceous species could be a cue in competitive shrub and tree dominated communities after fire. Keeley and Fotheringham (1998) hypothesized several mechanisms behind smoke induced germination. Increased solute permeability of the subdermal cuticle could enhance uptake of ions or gases that induce germination and could result in leaching of internal inhibitors, nitrates in smoke may trigger germination, acids in smoke

could lead to internal acidification and enzymes or growth regulators could be induced by smoke chemicals. Effects and applications of smoke water should be further researched for alternative approaches to boreal forest reclamation.

7.3.3 Effect of Potassium Nitrate

Potassium nitrate enhanced germination of 5 native boreal forest species (Table 7.3). It is well known nitrate can trigger seed germination, although the exact cause is not fully understood (Baskin and Baskin 2001, Giba et al. 2003). From an evolutionary perspective breaking seed dormancy by nitrate would operate as a gap detection mechanism if nitrate concentrations in the soil solution were so low in vegetation due to absorption of nitrate that germination was not stimulated (Pons 1989). It is not known whether nitrate in seeds alleviates dormancy directly or through metabolic changes (Keeley and Fotheringham 1998). The germination response to nitrate is highly influenced by other environmental factors, especially light and fluctuating temperatures (Vincent and Roberts 1977, Probert et al. 1987). Nitrate is generally more effective when seeds are exposed to alternating temperatures and exposed to light. More species responding negatively than positively to potassium nitrate was not expected, especially when nitrogen and/or nitrate concentrations typically increase after low to moderate intensity disturbances (Fisher and Binkley 2000, Frey et al. 2003). Keeley and Fotheringham (1998) found potassium nitrate induced dormancy of *Emmenanthe penduliflora* (whispering bells) had more to do with the high hydrogen ions in nitrate. Seeds of *Oryzopsis pungens*, *Schizachne purpurascens*, *Anemone multifida* responded the greatest to potassium nitrate; these three species had a positive response to potassium nitrate prior to stratification and a significant decrease in germination after cold stratification (Figure 7.4). The interactions of potassium nitrate and cold stratification are not well understood.

Eight species had a negative response to potassium nitrate, dependent on species, stratification type and smoke water (Table 3). Lack of germination in the presence of nitrate could be gap detection mechanism for certain species. Amount of

nitrogen lost is dependent on intensity or severity of disturbance (Johnston and Elliott 1998). Weber et al. (1985) found prescribed burning in an eastern Ontario jack pine ecosystem reduced forest floor nitrogen from 500 to 150 kg ha^{-1}.

Mechanisms in seed to detect potential competing plants and inhibit germination until these plants disappear (gap detection) are of considerable survival value, particularly for species depending on open space for regeneration from seed (Pons 1989). Inhibition of germination by allelopathic substances has been suggested as a mechanism for gap detection, but there is little conclusive evidence (Pons 1989). *Vaccinium myrtilloides*, *Anemone patens* and *Potentilla tridentata* had a negative response to potassium nitrate using non stratified and cold stratified seeds. These species are predominately found in nutrient poor jack pine forests on coarse textured soils and all responded positively to smoke water. They may have a gap detection mechanism and seed dormancy is reduced with elevated nitrate. There is evidence ericaceous shrubs are not capable of producing nitrate reductase and are unable to use nitrogen as nitrate (Smirnoff et al. 1984). Reduced abundance of ericaceous shrubs following fertilization of boreal forests (Albrektson et al. 1977, Kellner and Marshagen 1991, Prescott et al. 1995). Knellner (1993) suggested reductions in dwarf shrubs in repeatedly fertilized forests in Sweden could be attributed to competition from invading pioneer species. Prescott et al. (1995) showed reduction of *Vaccinium myrtilloides* with fertilizer was not caused by an increase in competition from pioneer species or shade. Giba et al. (2003) indicated inhibition of seeds to nitrogenous compounds is rare. The exact cause of nitrate induction and inhibition of seed germination is not well understood, but perhaps there is an evolutionary explanation. The effects and applications of potassium nitrate (or other nitrogen sources) should be further researched to determine alternative approaches to the restoration of disturbed boreal forest ecosystems.

7.4 CONCLUSIONS

This is the first study that has demonstrated the effects of smoke water on germination for a variety of boreal plant species. Smoke water reduced

germination of several species, but only for seeds that had been cold stratified. *Vaccinium myrtilloides* had the largest increase in germination using smoke water, but also had the most reduced germination using potassium nitrate. Most species had no response to potassium nitrate if seeds were not cold stratified; however, once seeds were cold stratified, potassium nitrate induced germination for 8 species. Interactions between smoke water, potassium nitrate and stratified seeds are not well understood. The applications of smoke water and potassium nitrate to reclaimed land could increase native species germination from direct placed topsoil on disturbed lands or be used to enhance germination of various native boreal plants in commercial nurseries.

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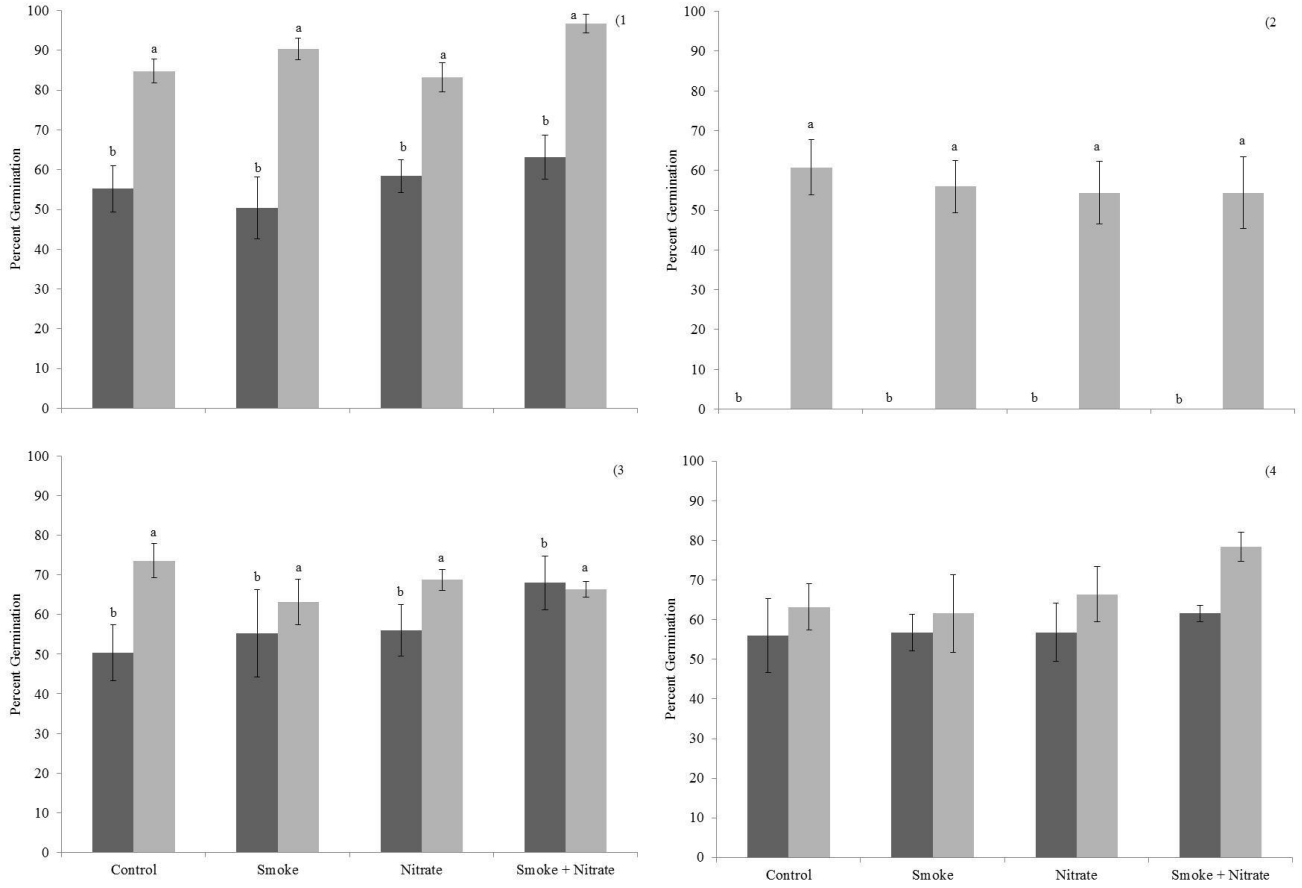

Figure 7.1. Germination of cold stratified (light gray) and non stratified (dark gray) seeds of *Bromus ciliatus* (1), *Cornus canadensis* (2), *Fragaria virginiana* (3) and *Elymus innovatus* (4) after exposure to treatment solutions. Treatments with different letters are significantly different at $p \leq 0.05$; n=5. Nitrate= potassium nitrate.

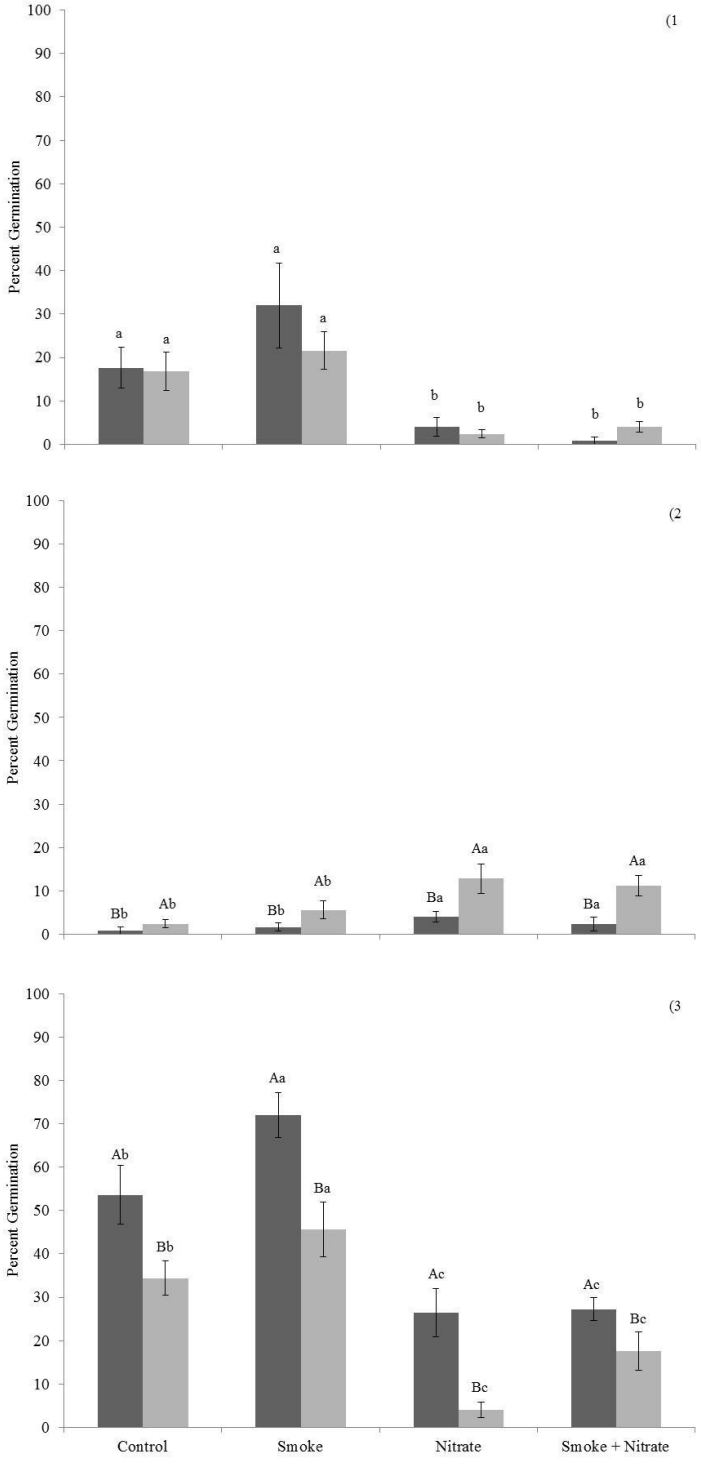

Figure 7.2. Germination of cold stratified (light gray) and non stratified (dark gray) seeds of *Potentilla tridentata* (1), *Shepherdia canadensis* (2) and *Vaccinium myrtilloides* (3) after exposure to treatment solutions. Treatments with different letters are significantly different at $p \leq 0.05$; n=5. Nitrate = potassium nitrate.

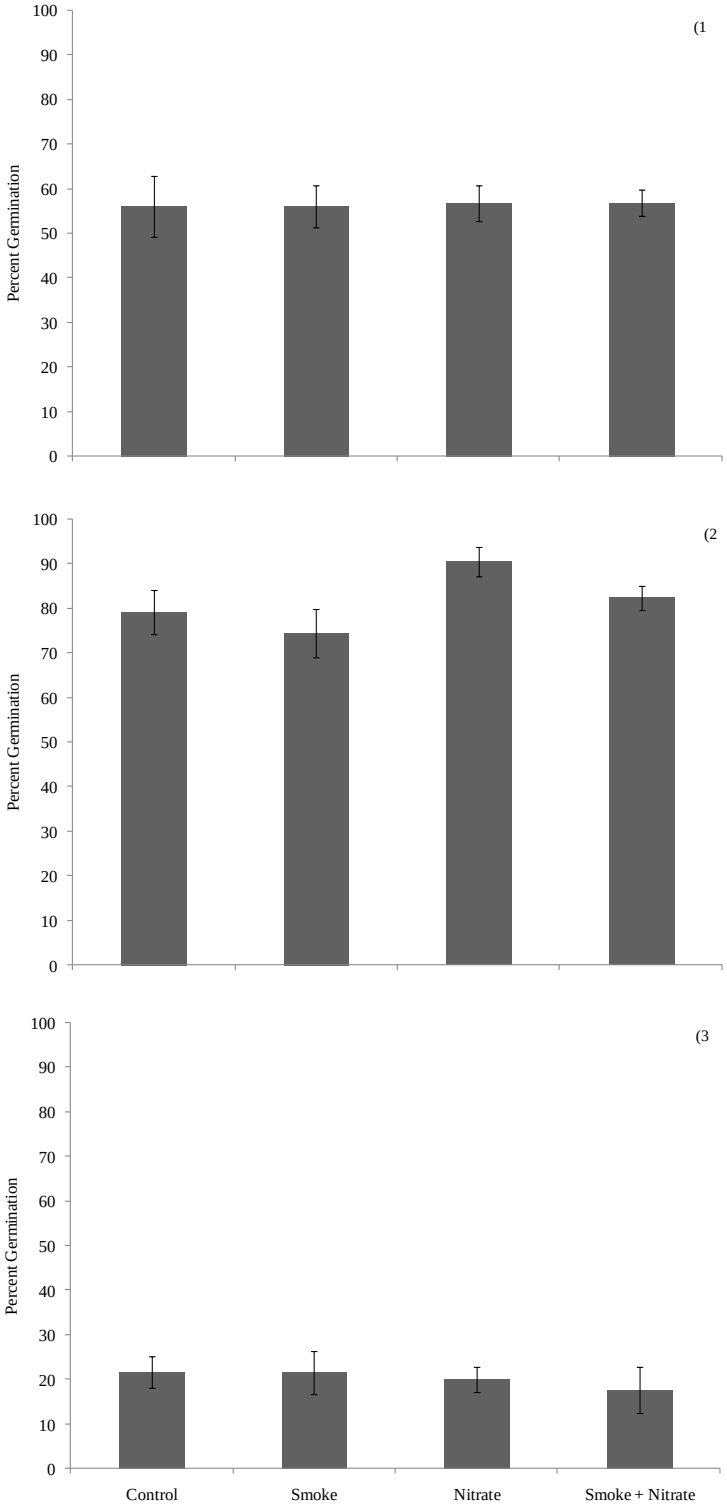

Figure 7.3. Germination of non stratified seeds for *Agropyron trachycaulum* (1), *Chenopodium capitatum* (2) and *Vicia americana* (3) after exposure to treatment solutions (n=5). Nitrate = potassium nitrate.

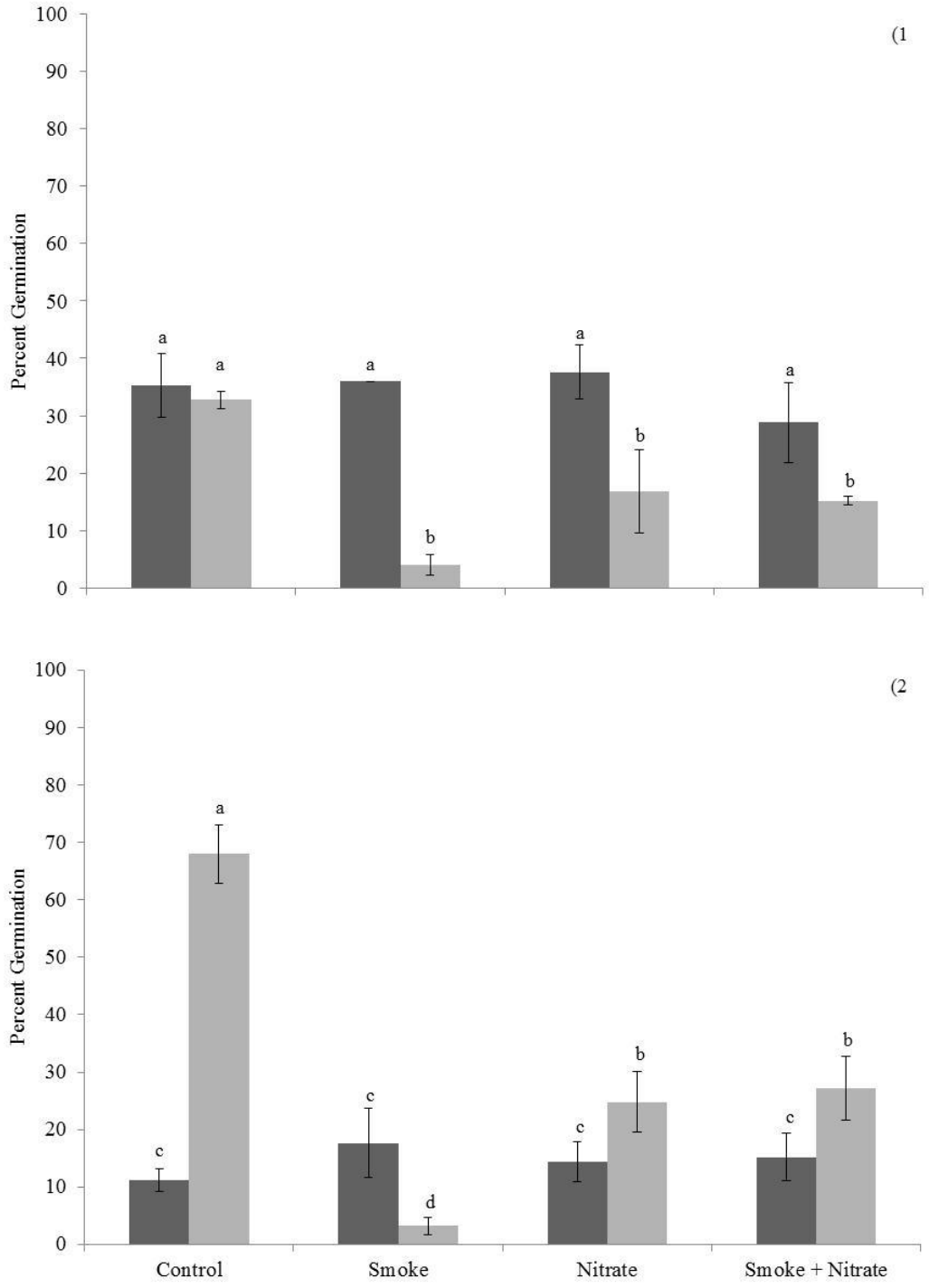

Figure 7.4. Germination of cold stratified (light gray) and non stratified (dark gray) seeds of *Anemone multifida* (1) and *Schizachne purpurascens* (2) after exposure to treatment solutions. Treatments with different letters are significantly different at $p \leq 0.05$; n=5. Nitrate = potassium nitrate.

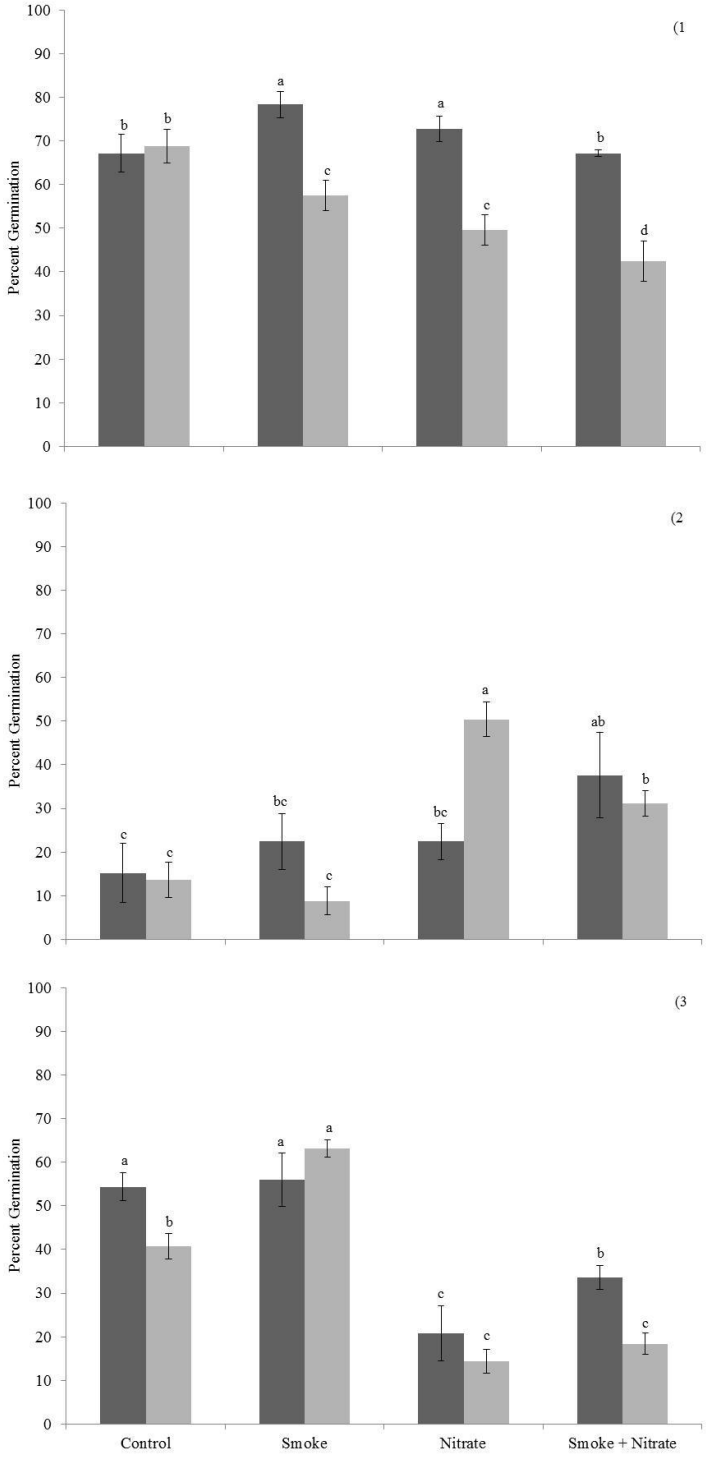

Figure 7.5. Germination of cold stratified (light gray) and non stratified (dark gray) seeds of *Oryzopsis pungens* (1), *Ribes hudsonianum* (2) and *Anemone patens* (3) after exposure to treatment solutions. Treatments with different letters are significantly different at $p \leq 0.05$; n=5. Nitrate = potassium nitrate.

Table 7.1. Taxonomic information for species used in the experiment.

Family	Latin Name	Common Name	Growth Form	Viability (%)
Chenopodiaceae	*Chenopodium capitatum* (L.) Aschers	Strawberry blite	Forb	98 (1.0)
Elaeagnaceae	*Shepherdia canadensis* (L.) Nutt	Canada buffalo berry	Shrub	90 (2.3)
Ericaceae	*Vaccinium myrtilloides* Michx	Blueberry	Shrub	72 (3.9)
Fabaceae	*Vicia americana* Muhl.	American vetch	Forb	90 (1.8)
Gramineae	*Agropyron trachycaulum* var. *trachycaulum* (Cassidy) Malte	Slender wheat grass	Grass	69 (3.7)
	Bromus ciliatus L.	Fringed brome	Grass	96 (1.5)
	Elymus innovatus Beal.	Hairy wild rye	Grass	73 (3.7)
	Oryzopsis pungens (Torr.) A.S. Hitchc	Jack pine rice grass	Grass	91 (3.4)
	Schizachne purpurascens (Torr.) Swallen	False melic	Grass	86 (2.3)
Grossulariaceae	*Ribes hudsonianum* Richards.	Wild black currant	Shrub	96 (1.5)
Liliaceae	*Maianthemum canadense* Desf.	Wild lily of the valley	Lily	91 (2.7)
Ranunculaceae	*Anemone multifida* Poir.	Cut leaved anemone	Forb	60 (3.8)
	Anemone patens L.	Prairie crocus	Forb	71 (2.3)
Rosaceae	*Fragaria virginiana* Duchesne	Wild strawberry	Forb	88 (2.1)
	Prunus pensylvanica (L.f)	Pin cherry	Shrub	93 (1.7)
	Rubus pubescens Raf.	Dewberry	Forb	87 (3.1)
	Potentilla tridentata Ait.	Three toothed cinquefoil	Forb	61 (3.9)
Umbelliferae	*Cornus canadensis* L.	Bunchberry	Forb	81 (0.9)

Data are mean and (standard error). n=4.

Table 7.2. Summary of p values from the two way ANOVA for germination applied to stratification and solution treatments.

Species	Stratification	Solution	Stratification x Solution
Chenopodium capitatum	-	0.0964	-
Shepherdia canadensis	0.0001	0.0041	0.1596
Vaccinium myrtilloides	< 0.0001	< 0.0001	0.3696
Vicia americana	-	0.8921	-
Agropyron trachycaulum	-	0.9987	-
Bromus ciliatus	< 0.0001	0.1237	0.4397
Elymus innovatus	0.0512	0.35059	0.8257
Oryzopsis pungens	< 0.0001	0.0014	0.0018
Schizachne purpurascens	< 0.0001	< 0.0001	< 0.0001
Ribes hudsonianum	0.6892	0.0002	0.0044
Maianthemum canadense	0.1123	0.0644	0.0644
Anemone multifida	< 0.0001	0.0171	0.0179
Anemone patens	0.0159	< 0.0001	0.0280
Fragaria virginiana	0.0249	0.6563	0.2880
Prunus pensylvanica	0.1892	0.5398	0.5398
Rubus pubescens	1.0000	0.7229	0.2808
Potentilla tridentata[2]	0.5754	< 0.0001	0.5629
Cornus canadensis	< 0.0001	0.9248	0.9248

[2] rank transformed for data analysis.

Table 7.3. Species response to various treatment solutions for non stratified and cold stratified seeds.

Species	No Stratification			Cold Stratification		
	Smoke	Nitrate	Smoke + Nitrate	Smoke	Nitrate	Smoke + Nitrate
Chenopodium capitatum	=	+	=	na	na	na
Shepherdia canadensis	=	+*	+*	=	+*	+*
Vaccinium myrtilloides	+*	-*	-*	+*	-*	-*
Vicia americana	=	=	=	na	na	na
Agropyron trachycaulum	=	=	=	na	na	na
Bromus ciliatus	=	=	+	+	=	+
Elymus innovatus	=	=	+	=	=	+
Oryzopsis pungens	+*	+	=	-	-*	-*
Schizachne purpurascens	+	=	=	-*	-*	-*
Ribes hudsonianum	+	+	+*	-	+*	+*
Maianthemum canadense	=	=	=	=	=	=
Anemone multifida	=	=	-	-*	-*	-*
Anemone patens	=	-*	-*	+*	-*	-*
Fragaria virginiana	=	+	+	-	-	-
Prunus pensylvanica	=	=	=	=	=	=
Rubus pubescens	=	=	=	=	=	=
Potentilla tridentata	+*	-*	-*	+*	-*	-*
Cornus canadensis	=	=	=	=	-	-

Na, not applicable. Nitrate- potassium nitrate. Symbols; = similar germination response between solution treatments (smoke, potassium nitrate and smoke + potassium nitrate) and control, + increased germination response (> 5 % mean seed germination) to solution treatments, decreased germination response (< 5 % mean seed germination) to solution treatments. Significant germination responses have asteriks.

CHAPTER VIII
SYNTHESIS

8.1 INTRODUCTION

Use of forest surface soil (LFH) for reclamation is well documented in subtropical, temperate and arid regions (Tacey and Glossop 1980, Iverson and Wali 1981, Grant et al. 1996, Holmes 2001, Zhang et al. 2001, Skrindo and Halvorsen 2008, Hall et al. 2010). However, its applicability and effects of various handling practices in the boreal forest have not been widely researched (Mackenzie and Naeth 2010). Significant gaps remain in understanding the balance between maximum and optimal soil salvage and placement depths for establishment of diverse self-sustaining native plant communities and creation of a sustainable cover soil. No studies have been conducted on effects of stockpiling LFH or surface soil on soil chemical properties and buried in situ seeds in the boreal forest. It is not known if plant derived smoke water enhances seed germination in boreal forest vascular plants and few studies have evaluated interactions of plant derived smoke water and potassium nitrate. This chapter briefly summarizes the current state of knowledge, contributions of this research and potential future research directions.

8.2 STATE OF KNOWLEDGE AND RESEARCH CONTRIBUTIONS

8.2.1 LFH Salvage

The importance of salvaging LFH has been recognized in the Athabasca Oil Sands Region. Conservation of LFH is critical for development of diverse, self-sustaining forested ecosystems on mined land as it provides an important source of native plant genetic material. Properties that make topsoil a superior reclamation material to overburden, organic substitutes or amendments include more nutrients, larger microbial populations, higher organic matter content, better structure and aeration and lower resistance to root penetration and water

infiltration (Power et al. 1979). LFH is essential for maintenance of nutrient cycles and productive forests (Fisher and Binkley 2000) as it contains an abundant source of macro and micro nutrients and provides a rich source of organic matter, propagules, microbial biomass and soil fauna (McMillan 2005, Battigelli 2006, MacKenzie 2006, Brown 2010). Salvage depth affects these properties.

Increasing salvage depth of LFH increases amount of underlying mineral soil, diluting the nutrient rich LFH layer with less nutrient rich underlying mineral horizon(s). Root and seed abundance decreases with depth in a natural soil profile, as does number of viable vascular plant propagules. Shallow salvage creates a surface soil on the reclaimed site with higher carbon content and higher plant available macro and micro nutrients than deep salvage. However, some plant available nutrients, such as phosphorous in Bm horizon, can be higher in deeply salvaged LFH. Shallow salvage does not imply salvaging only the LFH layer, as incorporating some mineral soil is important for creating a cover soil. The mineral horizon (Ae) of LFH helps preserve a sustainable cover soil in the event of a forest fire and provides nutrients and a medium for seeds and roots that provides good propagule to soil contact.

Shallow salvage results in faster recruitment of native plant species from in situ propagules than deep salvage (Tacey and Glossop 1980, Rokich et al. 2000). Effects of salvage depth are also applicable to non vascular plant species. Rochefort et al. (2003) found significantly greater capitula of *Sphagnum* spp. spreading 0 to 10 cm of peatland surface soil compared to spreading deeper layers. Generally in our research, placement of shallow salvaged LFH resulted in increased species richness, canopy cover and plant density than deep salvaged LFH. Plant response to salvage depth is more pronounced for fine textured soil. Species richness, plant density and canopy cover significantly declined when salvage depth increased from 10 to 30 cm with using LFH salvaged from a fine textured luvisolic soil. Salvage depths up to 60 cm improved plant establishment relative to controls without LFH; however, abundance and richness of native species was significantly less than with soils salvaged $\leq$ 30 cm. Increasing salvage depth of coarse textured soil from 10 to 30 cm does not have as great an effect on

woody species richness or density emerging from in situ propagules, although plant performance (canopy cover) is reduced due to reduced organic matter and nutrients from deep salvage. Salvage depths > 30 cm should be avoided, unless the LFH layer is deep enough to offset reduced organic matter with deep salvage.

Size of equipment and scale of operation resulted in different levels of control over salvage depth. For example, at plot scale, controlled salvage from 10 to 30 cm of a coarse textured surface soil resulted in fewer woody plants after placement. At an operational scale, there was less control during salvage and there were few differences in emerged woody plants. The added variation in salvage depth created using large equipment might not accurately reflect actual differences between shallow and deep salvage depths.

LFH salvaged from mesic ecosites had greatest species richness and canopy cover. LFH salvaged from a submesic ecosite had greater species richness, density and canopy cover for native and woody plants than LFH salvaged from a xeric ecosite.

8.2.2 LFH Placement

Direct placement of LFH is preferred to stockpiling because soil quality and structure are better maintained and reclamation costs are reduced and because seed viability, nutrients, organic matter and soil biota are degraded in stockpiles and are difficult to replenish. Transfer of an abundant and diverse pool of propagules containg species that are appropriate for revegetation of the reclaimed site that occurs after LFH is directly placed is critical in developing a sustainable and resilient plant community to future disturbacnes, because the placement of a viable propagule bank ensures buried seeds and vegetative propagules are present for future regeneration in the event of a disturbance. Buried seeds and vegetative propagules are the primary sources of revegetation in postdisturbance plant communities in natural forests (Whittle et al. 1997); therefore, direct placement of LFH emulates, as close as possible, to a natural forest compared to any of the

current alternative reclamation methods, such as peat or peat-mineral mix supplemented with seeding or transplanting nursery plants. .

Effect of placement depth on establishment of native plant species is influenced by LFH properties and propagule distribution in applied soil. Shallow placement generally resulted in no significant differences in plant density and species richness from deeper placement. With deep placement, deeply buried seeds and vegetative propagules are unable to emerge with limited resources such as carbohydrates and light (Benvenuti 2003). In our research, emergence from roots of three native boreal species decreased with increasing burial depth and few plants emerged when roots were buried at 10 cm. Deep placement generally resulted in greater plant cover and/or productivity than shallow placement. LFH salvaged from coarse textured surface soil at 10 and 25 cm had significantly higher woody and herbaceous canopy cover when placed at 20 cm than at 10 cm. Canopy cover of native boreal plants increased linearly with increasing placement depths of 0, 2, 5 and 10 cm using LFH on fine and coarse textured soil. Deep placement of LFH creates a rooting zone with greater organic matter content and available micro and macro nutrients; this increased plant canopy cover.

Chemical and physical properties of the substrate on which LFH is placed are important for providing the environment in which roots physically stabilize plants and extract water and nutrients. Substrate properties can affect plant growth due to pore water chemistry, available water holding capacity, organic matter, nutrient toxicities and deficiencies and thermal properties. Substrates available in the Athabasca Oil Sands Region include coarse and fine textured parent material and peat-mineral mix. Each substrate differs in available water holding capacity, soil temperature and nutrient availability. When surface soil is applied to good quality substrates with few limitations to plants, water and nutrient supply, differences in plant canopy cover between shallow and deep placements are fewer than when placed on substrates containing less organic matter, nutrients and available water.

Depth of placement should be based on reclamation objectives and optimal use of material if quantities are limited. Optimal placement depth to sustain a mature,

productive forest may be different than the depth required for diverse wildlife habitat. Important considerations for restoring productive forests are available soil water and growing space for tree roots (Rodrigue and Burger 2004). Deep soil positively influenced mine soil productivity through increased rooting depth and greater water holding capacity (Torbert et al. 1988, Andrews et al. 1998). Soil placement depth for a less productive forested plant community might be shallower than that for commercial forest. For increased species diversity, placement depths should be varied from shallow to deep (DePuit 1984); however, if propagules are buried too deeply they could lie dormant and lose viability or germinate but never successfully establish. If LFH is applied at shallow depths, propagules could emerge but available water and nutrients can limit plant productivity. A balance between maximizing the area over which propagules are redistributed while providing sufficient resources for successful plant establishment is needed. If high diversity within plant communities is a reclamation goal, topsoil should be applied at depths shallower than those necessary to maximize total diversity.

Operators should look for alternative opportunities to directly place LFH if there are no areas available for permanent reclamation to avoid stockpiling LFH. LFH could be used to enhance species diversity and establish more upland species on cover soils composed of peat-mineral mix that already have established plant communities that could benefit from the added plant species from LFH. For example, direct placement of LFH on peat-mineral mix improved establishment of diverse self-sustaining native plant communities. Although this method might seem counterintuitive, research suggests that this is a better alternative to stockpiling. LFH can be spread on directly placed peat-mineral mix or on older reclamation areas that have received peat-mineral mix. The benefit of placing LFH on areas previously reclaimed with peat-mineral mixes that do not have diverse or productive plant communities established is greater than if placed on areas with peat-mineral mix that have diverse or productive plant communities established. LFH should not be placed on former reclaimed areas that are or will be prone to soil quality degradation or on areas that would accelerate loss of

viable propagules (saline areas, saturated, flooded areas), because that could potentially limit species successfully establishing from LFH. Placing LFH on substrates with a viable propagule bank of undesired, competitive species should be avoided, unless placement depth is sufficient to prevent their emergence.

8.2.3 Stockpiling

Stockpiling negatively affects topsoil chemical, physical and biological properties. Stockpiling and associated disturbance from earth moving equipment increases soil bulk density and reduces aggregate stability causing degradation in soil structure (Hunter and Curie 1956). Over time, our stockpiles became anaerobic below the surface, reducing seed viability and germination and significantly altering nutrients susceptible to changes in redox conditions.In other research stockpiling reduced total nitrogen, available nitrogen and organic carbon content (Visser et al. 1984, Kundu and Ghose 1997) and significantly reduced mycorrhizae and other microbial populations (Harris et al. 1989). While stockpiled topsoil becomes biologically stagnant, (specifically for aerobic microorganisms, seeds and roots), there is little evidence to suggest LFH stockpiled in cool climates is stagnant.

In the boreal forest, stockpiling LFH for 16 months resulted in large increases with greater depth of concentrations of iron, ammonium, manganese and other soluble ions; however, stockpiling did not substantially alter total nitrogen or organic matter. Most available nutrients (ammonium, phosphorous, potassium) and soluble ions (calcium, potassium, magnesium) increased with storage depth and time. The most noticeable effect from stockpiling was the dramatic loss in seed and root viability. Stockpiling resulted in a significant decline (up to 100 %) in seed viability of 24 of 27 boreal species studied in both small and large stockpiles at depths below 1 m. Constructing temporary stockpiles, for less than 8 months, during frozen months has less negative effects on seed viability; however, when stockpiles thawed, seed viability rapidly declined. Stockpiling

was more detrimental to soil quality and seed viability using LFH salvaged from fine textured soil than coarse textured soils.

Stockpiles should be selectively placed on areas protected from saturation, excessive compaction from equipment and contaminants, which reduce soil quality (Ghose 2001). Stockpiling wet soils can increase soil degradation (Anderson et al. 1988). Storage time should be minimized to prevent soil degradation and to preserve propagule viability. Constructing several small stockpiles instead of just one large stockpile might be better for maintaining long term quality of LFH, because the surface area would be maximized. Propagule viability will be lost below the surface of stockpiles; therefore, increased surface area would provide a larger area for plants to reestablish a new propagule bank for salvage when the stockpiled material is required for placement. The surface (upper 30 cm) of stockpiles should be salvaged separately from the remainder of stockpiled material (LFH below 30 cm) for use in revegetation. Salvaging snow with LFH has short term benefits, by reducing microorganism activity, when stockpiled for less than one year. When the snow melts stockpiles become increasingly anaerobic. Too much snow incorporated with any type of stockpiled LFH creates an unstable stockpile and can cause the material to become saturated or very wet over time, thus more anaerobic.

8.2.4 Germination Enhancement

Frequent disturbances in boreal forest create opportunities for many species to germinate from the seed bank. Gaps created from disturbances change the environment through increases in soil temperature, light transmittance and soil nitrogen (Bonan and Shugart 1989). The stimulatory effects of nitrate and smoke water from plant derived burnt vegetation on seed germination are well known (Toole et al. 1956, Auchmoody 1979, Dixon et al. 1995, Roche et al. 1997, Bell 1999, Van Staden et al. 2004); however, little research has been conducted on the effects on native boreal shrubs and herbaceous plants. This is the first study that has demonstrated effects of smoke water on germination of a variety of boreal

plant species. From a revegetation perspective determining germination response through smoke and/or nitrogen additions from a wide range of species would be beneficial in promoting vegetation establishment on denuded landscapes.

Results from this study show that seeds of native boreal plants do respond to potassium nitrate and smoke water derived from burnt. Nine plant species had a positive response to smoke water derived from burnt vegetation. Smoke water reduced germination of four species, but only for seeds that had been cold stratified. *Vaccinium myrtilloides* had the highest germination with smoke water, but also had the lowest germination with potassium nitrate. Five plant species had a positive response to potassium nitrate and eight species had a negative response; most reductions in germination occured once seeds were cold stratified.

8.2.5 LFH Definition

There is confusion among academics, government and industry personnel and soil scientists over the term LFH. There is no consensus on the appropriate term. Objections to the definition we used in our research are due to confusion in distinguishing between LFH for use in reclamation and the LFH layer or horizon described by the Soil Classification Working Group in Canada (1998). Use of the term LFH alone can imply the organic horizon contains all three layers L, F and H; however, only one or two of the layers might be present.

Alternative terms to replace LFH are awkward, lengthy and do not emphasize the importance of the LFH layer or its origin, which is upland forests. The term forest floor is confusing because it does not distinguish between upland and lowland forests. Amending the term forest floor to include upland further lengthens the term. Using upland surface soil is vague in that it does not highlight what the surface soil is composed of, a similar complication with using only LFH. Replacing LFH with the term forest topsoil cannot be used universally throughout the boreal forest, because not all boreal forest soils have an A horizon.

For the scientific community, using the term LFH-mineral mix would reduce the confusion, because LFH is a mix of LFH and mineral soil. This is similar to how

the term peat-mineral mix is used. However, confusion about how to define the ratio of peat to mineral soil, either by depth or volume, remains. Further description of the LFH-mineral mix should include depths of the LFH layer and A horizon(s), if present, and soil texture of the mineral horizons mixed with LFH. Depth of salvage should be consistent among all researchers such that total salvage depth starts from the surface of the LFH layer. Distinguishing if the organic horizon is composed of only one or two of the horizons may be of value for some readers; however, is not necessary, because LFH is simply referring to an organic horizon developed on upland forests. A description of the plant community that existed prior to salvage should also be included. Thus the term LFH-mineral mix is recommended for scientific use due to its accuracy.

Emphasis of the LFH layer is extremely important when using the term in operational practice, because field operators understand the simplicity of the term and its significance related to salvage depth if salvage depth effects are explained. The term LFH is easily communicated among different disciplines in operations and different languages. The effectiveness in executing appropriate salvage depths can only be done when a target salvage depth is applied after the term LFH. Salvaging LFH to a depth of 10 cm would imply that the depth starts at the surface of the LFH layer until a 10 cm depth is obtained; this may or may not include mineral soil as it depends on the depth of the LFH layer. The majority of field operators, mine planners, engineers and project managers use the term and the definition of LFH as described in Chapter 1. For the practitioners this term is unlikely to change simply due to its simplicity in communication among a diverse group of different disciplines, providing the term is defined correctly.

8.2.6 Disturbance and Successional Theory

Disturbances are discrete events in time and space that alter the structure of populations, communities and ecosystems (Walker and del Moral 2003). Disturbances affect abundance of populations and species in a plant community. Disturbance also has an important influence on ecosystem level processes such as

biomass accumulation, energetics, primary and 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 has on populations, communities and ecosystems are related to 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.

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. 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 abiotic components of an ecosystem. Disturbance size can have a large impact on initial composition of the regenerating plant community; it affects the physical environment and arrival and survival of propagules (Turner et al. 1998). Centers of large disturbances are more likely to favour 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.

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. 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, Kenkal et al. 1997).

In recent literature, the consensus is that multi-directional successional pathways in boreal forest are more likely than a single successional pathway (Cook 1996, McCook 1994, Finegan 1984). Studies on dynamics of forest structure and composition have shown initial floristic composition (Egler 1954) and tolerance (Connell and Slatyer 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 availability of propagules constrain reestablishment following disturbance (Kenkel et al. 1997). Propagule availability is chiefly determined by random factors and site history, implying succession is heterogeneous (Kenkel et al. 1997).

Most disturbances created by oil sands mining are very large and intense, creating conditions for primary succession. Thus, conservation of reclamation material such as LFH and peat become important in speeding the trajectory and creating conditions more similar to secondary succession, because organic matter and nutrients are available soon after placement. Post disturbance succession in the boreal forest is believed to conform more closely to initial floristic composition than to the classical relay floristics model (Elger 1954, Kenkal 1997, Bergeron 2000). Applicability of these models of succession has not been tested on older reclaimed oil sands areas and many of the forests are considered young.

Direct placed LFH more closely resembles secondary succession of a naturally disturbed upland forest compared to placing peat or peat-mineral mix, because LFH contains appropriate species on post disturbance landscapes that are well drained. Frequency of disturbances caused by oil sands depends on mine operations and may be low to high. A plant community establishing from direct placed LFH would be much more resilient to future disturbances in reestablishing a diverse, native upland forest compared to peat or peat-mineral mix, because LFH contains native upland boreal forest plants. Seeds that do not emerge from

LFH are likely to remain viable for years making using direct placed LFH so important for reclaiming self-sustaining boreal forest communities.

The understory of post disturbed landscapes reclaimed with peat or peat-mineral can contain a high cover of herbaceous plants, native and non-native (*Calamagrostis canadensis* (Michx.) Beav., *Sonchus arvense* L.,), *Bromus inermis* Leyes (smooth brome), *Medicago sativa* L. (alfalfa), *Taraxacum officinale* Weber) considered competitive to more desired woody plants required for forest reclamation. There have been no soil propagule bank studies on older reclaimed post disturbed landscapes using peat-mineral mix; however, the propagule bank is likely to contain mostly herbaceous species present in the understory. In the event of disturbance on a post disturbed landscape reclaimed with peat or peat-mineral mix, competitive herbaceous plants could outcompete trees and other woody plants, keeping the plant community at an early seral stage for a longer time.

Relying solely on natural seed dispersal for revegetation may not be appropriate for large, intense disturbances because most species other than ruderals with wind dispersed seeds (*Epilobium angustifolium* L. (fireweed)) disperse several meters from the parent plant (Turner et al. 1998, Chambers and MacMahon 1994). Salvaging LFH for oil sands reclamation is highly recommended as it provides a direct route for propagule availability at the site and adds species best adapted to drier conditions, such as those on upland landscapes. It is advantageous to maximize diversity of native species by direct placing LFH at shallow and deep depths. It can be difficult to change vegetation composition once it becomes established. Invasion and colonization of native species can be very slow, and once a site is occupied by undesired species, survival rates of new, invading or transplanted desired species can be low; therefore, placement of greater depths may be advantageous to quickly establish desired native species from LFH.

8.3 LIMITATIONS OF THE RESEARCH

Statistical inferences are limited to the study area(s). The inferences from all experiments are limited to northeastern Alberta and inferences from large

experiments (donor soil transport experiments) are further constrained to a more defined area within the Athacasca Oil Sands Region. For example, the experiment in Chapter 2 and 3 was set up only on a north facing aspect and only on a lean oil sands overburden dump. It would have been ideal to have similar multiple experiments on more than one aspect, landform and mine. That was not possible due to constraints with availability of donor sites and placement sites and budgets. The research described in Chapter 4 attempted to construct similar experimental plots at different mines; however, this was at the expense of reducing the size of plots and the experimental plots were set up by hand. Larger experimental plots using mine equipment could be applied to other sites in the future to better extrapolate the data beyond the current study sites.

Plant communities established in the various treatments and experiments and changes to soil chemistry were assessed for only a few years. In some cases experiments were partially or wholly destroyed due to further mine development and continued monitoring would not be possible. Long term monitoring would allow us to determine treatment differences over time and help evaluate sustainability of various treatments over time. Long term monitoring can only be done if experiments are set up in locations that will not be redisturbed in the future; therefore, research projects should be situated at locations that have a low risk to anthropogenic disturbances.

The broad range of parameters for characterization of different treatments and substrates were not assessed for each experiment; these include, water holding capacity, soil water content, soil temperature and chemical properties such as available nutrients and soluble ions. Properties not assessed in any of the experiments include bulk density, hydrophobicity, aggregate stability, microorganisms and chemical properties with smoke water. Time and funding were not available in this research program, but should be included in further research or longer term monitoring programs.

A broad range of levels for most factors were not incorporated into the research, thus limiting inferences and extrapolation to only the levels tested. For example,

smoke water derived from only one type of plant material and only one concentration was tested to determine its effects on seed germination. Experiments using large mining equipment only had two salvage and placement depth comparisons. Research focused on answering questions specifically related to seed germination can be established. Experiments that utilize alternative designs to ANOVA, such as regression, could be set up to exlore the influes of different depths of salvage and placement.

8.4 RESEARCH GAPS

8.4.1 LFH Salvage

This research focused on effects of salvage depth on plant establishment and soil chemistry for only three years; longer periods are required to determine how salvage depth affects sustainability of cover soil from LFH. Due to recent applications of upland surface soil there are limited data for us to know conclusively how to best handle upland surface soil. It is critical that research projects and large scale operational projects are long term to provide operators with a better understanding of how various salvage and placement practices affect long term sustainability of soil quality and plant communities.

Effects of salvage depth of fine textured surface soil should be researched at a larger scale that represents operational practices. Results obtained from small plots might not accurately represent the operational outcome. Effects of salvage depth on other biotic variables such as soil micro, meso and macro fauna also need to be investigated. This research did not assess physical properties of soil other than texture; therefore, additional studies are required to characterize how they are impacted by salvage depth.

The literature suggests that fall and winter salvage is best for maximizing plant establishment based on higher carbohydrate reserves contained within roots during these seasons; however, there is no rigorous research on this. Syncrude Canada Ltd. studied summer versus winter salvage, but the experiment was not

set up to answer this question, only addressing direct placement during winter versus summer salvaged LFH stockpiled for three to four months (Lanoue and Qualizza 1999). Season of salvage is an important factor to investigate to test what has been suggested. Not salvaging during summer months can lead industry to salvage later during the year and miss opportunities for direct placement.

Young and mid-seral forests have a more abundant and diverse propagule bank than late seral forests (Moore and Wein 1977, Warr et al. 1993). Harvesting old growth forest years in advance of soil salvage could increase abundance of the propagule bank; however, the time interval between harvesting and soil salvage (for the purpose of increasing regeneration success) needs to be further studied. Effects of sprouting in trembling aspen and other boreal deciduous trees are most vigorous when total nonstructural carbohydrate reserves are at their highest (Peterson and Peterson 1992, Landhäusser and Lieffers 1997, Landhäusser and Lieffers 2003, Frey et al. 2003). Winter logging usually promotes abundant suckering and best growth compared with spring or summer harvest (Peterson and Peterson 1992). The time between tree harvest and soil salvage can have an effect on sprouting of trembling aspen. MacKenzie (2006) salvaged LFH on fine textured soil dominated by *Populus tremuloides* Michx. (trembling aspen); the trees were harvested two growing seasons prior to LFH salvage and few *Populus tremuloides* emerged after placement. In this research (Chapters 2 and 3) trees were harvested < 1 year before LFH salvage and many *Populus tremuloides* emerged in various treatments. Although soil texture and site characteristics could affect regeneration of *Populus tremuloides*, carbohydrate reserves of *Populus tremuloides* in this research might have been greater compared to MacKenzie (2006), thus resulting in higher densities of *Populus tremuloides.*

Farming the LFH layer could provide additional sources of propagules for revegetation. This involves leaving residual seed and roots on site after the LFH layer has been salvaged. The propagules produce new seedlings that grow and mature to develop a new soil propagule bank. The soil water and soil nutrient regimes of the site determine how quickly a new forest floor begins to develop. This technique has not been validated; however, it may be a viable collection and

propagation system in the future. Further research is needed to determine which species have a positive and negative response to this technique to establish its effectiveness. A cost-benefit analysis and impacts on soil quality should be completed before implementing this practice on a large scale.

8.4.2 LFH Placement

This research studied the effects of placement depth on plant establishment and soil chemical properties for three years, longer periods are required to determine how salvage depth affects sustainability of cover soil from LFH. Very shallow placement of LFH needs to be studied at an operational scale, as results from this research indicate there is potential for even very shallow placement of LFH to be used as an effective seed source on various substrates. This research did not assess maximum placement depth; however, depth of natural soil profiles in the region could give some indication of what might be too deep. Placement of a uniform depth might not be the most effective way of establishing diverse native plant communities; therefore, effects of variable placement depths should be assessed to maximize diversity at a landscape scale.

On a localized scale, optimal size for placing individual LFH patches is unknown. Creating small islands might not be desirable if there is risk of losing desirable native species to competitive undesired herbaceous plants ingressing from adjacent reclamation areas. Placing LFH in one large island might not maximize native plant egress; however, native plant egress should be evaluated at a landscape scale.

Placing salvaged small plugs of LFH with upper Ae horizon on areas reclaimed with peat-mineral mix requires study. Placement of plugs results in high establishment of targeted shrub species (MacKenzie and Renkema 2011). Using plugs from LFH planted immediately adjacent to planted trees would provide a source of nutrients and mycorrhizae for the planted trees and inoculation of seeds, roots and microorganisms on peat-mineral mixes.

8.4.3 Stockpiling

Stockpiling effects in the Athabasca Oil Sands Region have only been studied for a short time and long term data will be required to formulate stronger conclusions about changes to soil quality over time. This research only used LFH, and there is little known about effects of stockpiling peat and peat-mineral mix. This research did not assess effects of stockpiling on soil fauna. Some studies suggest microbial populations of stockpiled topsoil return quickly once stockpiled LFH is placed (Williamson and Johnson 1990); however, it is unknown if microbial populations would return quickly using boreal forest surface soils. Maintaining seed viability may be possible if stockpiles can remain completely frozen or dry and cool during storage, keeping a stockpile frozen would be more feasible and achievable. Cause of seed death has been attributed to anerobic or anoxic conditions in combination with increasing soil temperatures and soil water content in large stockpiles. Determining the exact cause of loss in seed viability would help determine more feasible methods for constructing stockpiles that maintain seed viability.

It is unknown if a stockpile could be constructed to provide a constant supply of native propagules. Periodic removal and placement (on mined land) of the upper surface layer of the stockpile could help preserve and create an additional source of propagules. Constructing stockpiles to create a propagule source involves repeated salvage of the upper surface layer of stockpiled soil, which contains the only significant source of viable propagules.

Revegetating stockpiled LFH after replacement could be challenging due to changes in aggregate stability, organic matter quality, biological activity, soil chemistry, nutrient forms and availability. Placed stockpiled soil could need to be inoculated with microorganisms to help replenish the soil. It is not known how many available forms of nutrients will be lost to leaching or volatilization, uptake by plants or fixed back into exchangeable and non-exchangeable forms. Research on the effects of stockpiling on soil quality after it is replaced and methods for mitigating erosion and poor vegetation establishment will be required.

8.4.4 Germination Enhancement

Interactions between smoke water, potassium nitrate and stratified seeds is not well understood. Only one concentration was used for each treatment solution and seeds used were not freshly picked. Effects and applications of smoke water and potassium nitrate (or other nitrogen sources) should be further studied to determine alternative approaches to revegetation of boreal forest ecosystems.

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