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Use Of Woody Debris As An Amendment For Reclamation After Oil Sands Mining

by

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ABSTRACT

This research determined if woody debris amendments facilitate land reclamation after oil sands mining. Specifically, it assessed if woody debris affects vegetation cover and richness, woody species survival and abundance, soil nutrients, temperature and water, microbial biomass carbon and mycorrhizal biomass. A four year old site and a two year old site were used to compare treatments with and without woody debris. Woody debris did not affect initial vegetation emergence, but increased species richness and decreased introduced species cover. After winter assessments found woody debris cover positively associated with vegetation cover. More saplings planted on woody debris treatments survived and woody debris cover was positively associated with woody plant abundance. Woody debris treatments had lower soil nitrogen and higher phosphorus, suggesting nitrogen immobilization and leachate high in phosphorus. Soil under woody debris had a lower temperature range and higher soil volumetric water content. No differences were found in microbial parameters.

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CHAPTER I. INTRODUCTION

1. BACKGROUND

Boreal forests in the Athabasca Oil Sands Region are currently undergoing severe ecological disturbance due to the oil sands industry. After mining, oil sands companies must reclaim all disturbed land to predisturbance ecosystems with equivalent land capability. Current reclamation methods revolve around topsoiling, or reapplication of salvaged soil to disturbed land.

Adding woody debris to degraded oil sands landscapes may improve reclamation success by aiding and quickening recovery of meso fauna, microorganisms, soil nutrients, soil water and floral diversity. Woody debris may provide a source of plant seeds and propagules, create microsites where ecosystem function can persist and decrease erosion. Invertebrates and microorganisms that accompany woody debris can enhance soil formation processes. This research was undertaken to determine if woody debris can improve reclamation success of severely degraded land; specifically to determine if applying woody debris to a degraded landscape will increase native vegetation cover and diversity, aid soil nutrient cycling, temperature and water and increase microbial biomass.

2. BOREAL FOREST ECOSYSTEM

Boreal forests cover over 14.7 million km^2, or 11% of the earth's terrestrial surface (Bonan and Shugart 1989), mainly between 50° and 65° N latitudes (Molles 2002). Boreal forest covers 310 million ha across Canada, 30% of the land mass. The climate is seasonally variable with short, warm, moist summers and long, severely cold, dry winters (Bonan and Shugart 1989). Precipitation is usually moderate, ranging from 200 to 600 mm annually (Molles 2002).

Boreal forest soils usually have low fertility and are thin and acidic, resulting in slow decomposition rates (Molles 2002). Northern boreal forests can produce a permafrost layer due to cold soil temperatures. Permafrost is found under approximately 20% of the earth's surface and 50% of Canada and Russia. Tree biomass is generally comprised of coniferous and deciduous species. With a short growing season, low sun angle and low nutrient availability, tree growth is slow and vegetation productivity is low (Bonan and Shugart 1989).

Lichens are a common ground cover component in boreal forests throughout North America and Eurasia on high latitude or dry, sandy, nutrient poor, acidic soils. They are important in water retention, can fix nitrogen and can act as an insulator to keep the forest soil cold and protect the permafrost layer (Bonan and Shugart 1989). Cold, acidic soil created by lichens can inhibit organic decomposition and a thick lichen layer can impede tree growth. Mosses are the dominant ground cover in moist, shaded woodlands. Moss contributes to accumulation of organic material, increased soil water and decreased soil temperature and available nutrients. Nutrients are pooled by the moss layer and do not become available to vascular plants until moss dies and decomposes (Bonan and Shugart 1989).

Canadian boreal forests contain 35% of the world's wetland habitats and the largest peat ground cover in the world. These forests perform vital ecological functions such as carbon storage and climate regulation, while supporting high biodiversity (Woynillowicz et al. 2005).

3. DISTURBANCE AND SUCCESSION

Succession theory has been modified numerous times since first proposed by Frederic Clements to explain a predictable and uni-directional community progression toward a climax state, with little dependence on disturbance (Cook 1996). Succession is now perceived as a far more complex and erratic process, with strong dependence on disturbance regime (Pickett 1976, Cook 1996).

Modern successional theory involves various ecosystem components, including disturbance (Cook 1996). According to modern theory, disturbance is frequent and significantly influences floristic dynamics. Disturbance can affect succession by facilitating pathways to climax, including allowing retrogression, acceleration through stages, ceasing progression, or not allowing a stable climax. Random community variables and life histories can explain successional movement.

Different variables on closely related sites can drive succession at different times. As disturbance severity increases, new regeneration niches are created, allowing increased biodiversity and delayed competitive exclusion. Biodiversity increases until disturbance reaches a severity level where all forest understory species are destroyed and diversity decreases (Haeussler et al. 2002).

Equilibrium can be reached when small disturbances are balanced by regrowth. However, equilibrium may be impossible due to large scale or irregular disturbance, ephemeral events with long term residual negative effects, or altered ecosystem structure from climate change (Sprugel 1991). Ecosystem degradation results from any event or process that diminishes the ecological value of an ecosystem, or restricts ecosystem recovery toward equilibrium (Haeussler et al. 2002). In Canadian boreal forests, fire is the main natural disturbance (Bonan and Shugart 1989) and oil sands mining is the main anthropogenic disturbance (Renault et al. 2000, Purdy et al. 2005).

4. OIL SANDS DISTURBANCE

The oil sands industry causes severe anthropogenic disturbance to Canadian boreal forests. Oil sands contain bitumen, quartz sand, silt, clay and water. Bitumen is removed by mixing with hot water and caustic soda (National Energy Board 2000). Compared to crude oil, bitumen is heavier, more viscous and hydrogen deficient. Upgrading is required for bitumen to become marketable synthetic crude oil (Alberta Department of Energy 2006).

Canada has the most soil bitumen in the world (National Energy Board 2000) and 15% of world oil reserves, second only to Saudi Arabia. The majority is found in northern Alberta where deposits underlie 140,200 km², separated into Peace River, Athabasca and Cold Lake regions (Alberta Department of Energy 2006). Large scale mining began in 1967, but was not profitable until 1995 (Deming 2000). Bitumen production is rapidly growing and in 2005 output averaged more than 1 million barrels per day (Alberta Department of Energy 2006).

Bitumen is produced via mining or in situ methods. Mining involves removal of oil sands from large pits and transportation to cleaning facilities to separate bitumen

(Alberta Department of Energy 2006). If ore is too deep for mining, bitumen is recovered with in-situ methods similar to conventional oil extraction operations, with wells and pipelines. Approximately 4,800 km^2, or 20% of the land covering oil sands deposits, can be surface mined. This area is located in the Athabasca Oil Sands Region, north of Fort McMurray (Government of Alberta 2009).

Before oil sands mining can begin, several ecological layers need to be removed to expose the oil sands layer. This removal severely degrades and alters the ecological integrity of the land. Surface vegetation is removed and the water laden muskeg common in northern boreal forests is drained and removed. Suitable topsoil is separated and salvaged for later reclamation projects. Lower overburden consisting of rock, clay and barren sand is removed, exposing the underlying oil sands layer, usually occurring at 40 to 60 m depths. This process in addition to the construction of supporting infrastructure, roads and pipelines, contributes to overall land degradation (National Energy Board 2000). Thus far, over 600 km^2 have been disturbed (Government of Alberta 2009).

One major detrimental product of bitumen production is fine tailings, fine grained material mixed with residual bitumen, which is discarded into large holding ponds (National Energy Board 2000). Fine tailings make the soil saline, increase pH and total organic carbon, sodium, chloride, sulphate, boron, aluminum and soluble fluoride concentrations. Available nitrogen is reduced by hydrocarbon degrading microorganisms. All this negatively affects seedling growth and development, making reclamation difficult (Renault et al. 2000), leading some to believe it is unrealistic for pre and post disturbance plant communities to be similar (Purdy et al. 2005, Woynillowicz et al. 2005).

5. OIL SANDS RECLAMATION

Oil sands operations are regulated by Alberta Energy Resources Conservation Board (ERCB) and Alberta Environment (AENV). The EUB acts under the Energy Resources Conservation Act and the Oil Sands Conservation Act. AENV acts under the Environmental Protection and Enhancement Act (EPEA), the Water Act and the Public Lands Act. Under EPEA, oil sands companies are required to restore all disturbed land to predisturbance self sustaining ecosystems with comparable biodiversity (National Energy Board 2000). Throughout oil sands production, the Alberta government aims to achieve full value from mineable oil sands, while sustaining adjacent environments and returning disturbed areas to self sustaining boreal forest ecosystems (Alberta Department of Energy 2005).

Topsoiling, or reapplication of salvaged soil to spoiled land, is a reclamation effort often used in mining reclamation (DePuit 1984, Winter Sydnor and Redente 2002). Soil salvage has been a valuable source of native seeds and propagules (DePuit 1984, Winter Sydnor and Redente 2002, MacKenzie and Naeth 2007), and is important in the establishment of mycorrhizal associations (Palmer 1992). Topsoiling can increase soil organic matter, above ground biomass, nutrient availability and soil microorganisms and improve soil water holding capacity (Winter Sydnor and Redente 2002).

Topsoiling is commonly used in oil sands reclamation. The two main types of soil material used are peat mineral mix and upland surface soil. Peat mineral mix includes an organic peat horizon with underlying mineral soil (Singh 2007), usually at a proportion of 0.4 m mineral soil to 1 m peat (Oil Sands Revegetation Reclamation Committee 1998). Upland surface soil is a mix of the LFH horizon with underlying A horizon, sometimes including a portion or the entire B horizon (Singh 2007). LFH is a thin organic horizon common in upland forests composed of identifiable litter (L), fragmented and fermenting litter (F) and humus (H) with small amounts of moss (MacKenzie and Naeth 2007). MacKenzie and Naeth (2007) compared the two types of topsoil and analyzed application depths of 10 and 20 cm. Peat has been the main topsoil amendment used in oil sands reclamation due to its high organic matter content and availability in the area. Upland surface soil is now considered an improvement due to its greater content of plant propagules. Upland surface soil contains more seeds and produces a greater propagule density. An application depth of 20 cm of LFH resulted in the densest plant community establishment compared to other cover soil and depth treatments (MacKenzie and Naeth 2007).

When reclamation started at Suncor in 1971, hydroseeding of grasses and legumes was used to control erosion. Suncor now aims to create a self sustaining ecosystem that integrates into the surrounding environment. Instead of seeding grasses which can outcompete trees, shrubs and forbs, a nurse crop of

Hordeum vulgare L. (common barley) is seeded on reclamation sites. Barley is an annual cereal crop that provides erosion control and produces litter and root biomass that will help control erosion through future growing seasons (Oil Sands Revegetation Reclamation Committee 1998).

6. ASSESSING RECLAMATION SUCCESS

The best measure of understanding of an ecological system is how well it can be reconstructed from its parts (Thompson et al. 2001). Reclamation is defined as the process of converting a disturbed land to its initial land use or to one of equivalent capability (Powter 2002). Reclamation is a broad term that can encompass restoration, rehabilitation, revegetation and remediation. The Society for Ecological Restoration defines ecological restoration as the process of assisting the recovery of an ecosystem that has been degraded, damaged or destroyed (SER 2004). The society released a primer listing nine ecosystem attributes that successfully restored systems should display. These attributes include: similar diversity and community structure as a reference site; vegetation composition of mainly indigenous species; presence of functional groups necessary for sustainability; capability to sustain reproducing populations; presence of functions appropriate to successional stage; suitable integration in the landscape; reduced or eliminated threats to ecosystem integrity from surrounding areas; resilience to disturbance; and self sustainability.

Ruiz-Jaen and Aide (2005) reviewed articles published in Restoration Ecology to determine attributes typically used to assess restoration progress. Most studies concentrated on one or more of three major ecosystem attributes: diversity; vegetation structure; and ecological processes. Of the studies that evaluated restoration success after seeding or planting, 3% analyzed one attribute, 59% measured two attributes, and 38% analysed all three attributes (Ruiz-Jaen and Aide 2005). Vegetation biomass, diversity and density were most often assessed and ecological functions most often ignored. Short term plant monitoring often incorrectly predicted restoration success, indicating more emphasis is needed on monitoring ecological function. Restoration monitoring should include at least one indicator of ecological processes (Herrick et al. 2006).

7. ASSESSING SOIL QUALITY

The main functions of soil are to act as a substrate for plant growth, as an environmental buffer and as a regulator of water flow. Various physical, chemical and biological properties interact to contribute to these functions (Kneopp et al. 2000). Kneopp et al. (2000) proposed four indicators to assess soil quality for performing the above functions. These indicators include nitrogen availability, carbon availability, faunal populations and litter decomposition and forest floor characteristics. However, they noted that choosing indicators is difficult due to the many variables that influence each indicator and their interrelatedness.

Soil aggregation can indicate soil health since aggregates facilitate nutrient cycles and control erosion (Miller and Lodge 1997). Soil aggregation is highly dependent on bacteria and fungi and their decomposition of plant material. Bacteria, fungi and roots can produce polysaccharides that bind and stabilize soil aggregates. Hyphae from mycorrhizal and saprotrophic fungi, along with plant roots can further bind soil particles and micro aggregates into larger aggregates. These soil aggregates are important to the creation of a nutrient reserve and their formation should be a goal in restoration practices (Miller and Lodge 1997).

8. USE OF WOODY DEBRIS IN RECLAMATION

Peat mineral mix and upland surface soil are currently used as soil amendments in the Athabasca Oil Sands Region and are responsible for supplying seed bank, nutrients and microbial diversity. Upland surface soil is considered better due to its greater concentration of woody organic matter and plant propagules. Adding woody debris to a reclamation site would increase the supply of woody organic matter and potentially accelerate reclamation progression.

Woody debris is defined as all dead woody material in a forest ecosystem. This includes wood on the forest floor such as logs, fallen limbs, twigs and woody fruit; wood below ground such as dead roots and buried wood; and standing wood such as snags and stumps (Pyle and Brown 1999). Woody debris can be termed logging waste, slash residue, forest residue or habitat logs (Brennan et al. 2005).

Ecological value of woody debris was historically underestimated as evidenced by its removal from managed forests (Harmon et al. 1986, Debeljak 2006). It is now known to have important ecological value, providing erosion control (Stevens 1997, Whisenant 2005, Debeljak 2006), providing habitat and shelter for organisms (Graham 1925, Harmon et al. 1986, Brennan et al. 2005, Debeljak 2006), increasing microbial presence (Harmon et al. 1986, Pyle and Brown 1999, Hicks et al. 2003), aiding nutrient cycling (Harmon et al. 1986, Pyle and Brown 1999, Hicks et al. 2003, Hafner et al. 2005) and increasing plant growth (Christy and Mack 1984, Hofgaard 1993) and productivity (Debeljak 2006).

Although there is general agreement on the value woody debris provides to an ecosystem, little research has been conducted to analyze the processes resulting from placing woody debris on a severely disturbed landscape. Woody debris may improve soil quality by forming microsites for microorganisms and meso fauna that are important in nutrient processing and cycling. It may help severely degraded land regain ecological function by aiding, and quickening, recovery of meso fauna, microorganisms, soil nutrients, soil water and floral diversity.

9. WOODY DEBRIS CHARACTERISTICS AND CLASSIFICATION

Researchers classify woody debris differently, depending on their study. This is especially true for coarse woody debris (Yan et al. 2006). Harmon et al. (1986) first classified coarse woody debris as dead woody material with diameters $\geq$ 2.5 cm. Others used diameters > 7.5 cm or 9.5 cm. The USDA Forest Service and Long Term Ecological Research agreed on a common definition for coarse woody debris as that with a diameter $\geq$ 10 cm and a length $\geq$ 1 m. Woody debris with a diameter between 1 and 10 cm is classified as fine woody debris. Stumps and roots above ground are classified as coarse root debris (Yan et al. 2006).

Most studies on coarse woody debris categorize it by decay class. Classes typically range from 1 to 5, with 1 being freshly fallen and 5 being almost completely decayed. Structural integrity of heartwood and sapwood is usually the basis for classification (Table 1) (Brunner and Kimmins 2003, Yan et al. 2006), but wood density has also been correlated to decay class (Siitonen 2001).

Woody debris can be quantified by volume (Siitonen 2001), biomass or area percent cover (Harmon et al. 1986, Ståhl et al. 2001). Volume estimates assume logs are circular and use three methods to account for changes in diameter that occur with length. These include using standard volume functions developed for the tree species, sectioning the log into partitions and determining average length and diameter of each, and using taper functions (Ståhl et al. 2001). Siitonen (2001) composited several coarse woody debris volume estimates for spruce dominated old growth forests. Southern and middle boreal forests averaged 90 to 120 m^3 ha^{-1} and northern boreal forests averaged 50 to 80 m^3 ha^{-1}. Biomass can be estimated by multiplying average density for tree species by log volume, however, values can be inaccurate since decay class is rarely taken into account (Harmon et al. 1986). Ground area cover of woody debris is important since it quantifies the soil and wood interface. Area cover can vary greatly depending on forest type and age. An upper limit for temperate ecosystems is 14 to 25% cover in *Pseudotsuga-Tsuga* forests in the Pacific Northwest. A lower limit is 1.6 to 2% in *Quercus* forests in eastern North America (Harmon et al. 1986).

Many studies on coarse woody debris focus on decay rate and decomposition. Harmon et al. (1986) proposed the equation $Y_t=Y_0e^{-kt}$ to quantify rate of log decay. In this equation, Y_0 represents initial quantity of woody debris, Y_t represents quantity of woody debris remaining after time t, and k is the decay rate constant, or percent of wood decaying each year (Harmon et al. 1986). Decay rate constant is affected by tree species, log diameter, ground contact, air temperature, precipitation and soil water. These parameters influence fungi, invertebrate and microorganism activities as they decompose (Siitonen 2001).

Woody debris decay often starts while the tree is still standing and is initiated by fungal colonization (Boddy 2001). Once a tree falls, the first decomposition phase lasts about 5 years, depending on time for organisms to colonize and for a moisture status suitable for decomposition to be reached (Laiho and Prescott 2004). Different tree species may decompose at different rates and harbour varying microorganisms. Broad leaved trees generally decompose faster than conifers and harbour more microorganisms and invertebrates due to higher concentrations of sugar, amylum and protein which are easier to decompose than lignin in conifers (Zhou et al. 2007). *Picea mariana* Mill. BSP.(black spruce) and *Populus tremuloides* Michx. (trembling aspen) are common to the Canadian boreal forest and differ in decomposition pattern. *Populus tremuloides* will often decay on the inside first, forming ground hallows more frequently than other boreal tree species (Siitonen 2001).

10. ECOLOGICAL IMPACT OF WOODY DEBRIS ON BIOTIC COMMUNITIES

Woody debris provides habitat, food and reproductive opportunity to a variety of organisms (Graham 1925, Harmon et al. 1986). Logs offer shelter, nesting and foraging sites for reptiles, mammals, birds and invertebrates. Reptiles and birds use logs for basking and perching (Brennan et al. 2005). Abundance of several invertebrates and small mammals is positively correlated with proximity to woody debris, suggesting addition of fallen logs to a degraded landscape can assist in earlier recolonization of faunal species (Brennan et al. 2005).

Saproxylic species are dependent on dead or decaying wood during at least part of their life. This group includes animal, plant and fungal species that comprise 20 to 25% of total forest inhabitants. This percentage increases considerably if vertebrates that utilize dead wood as nesting habitat are included. Vertebrates included are mainly those that feed on saproxylic species. The most abundant saproxylics are the macro-fungi, comprising approximately 1500 wood decomposing species. Large diameter, intermediately decayed wood harbours the most saproxylic species (Siitonen 2001). Most organisms are found in inner bark and cambium layers which contain the greatest nutrients (Graham 1925).

Organisms living in woody debris change as physical and chemical properties of woody debris change (Graham 1925, Harmon et al. 1986, Siitonen 2001). The first successional stage starts after tree fall and lasts approximately two years. In Fennoscandia boreal forests, bark and other beetles (Scolytidae) are the first to colonize. They usually carry decomposers and attract other secondary phloem feeding species that quickly colonize the cambial zone. Some beetle larvae dig tunnels deep into the wood, creating a path for decomposer fungi to penetrate. Through successional stages, wood is decomposed in the order of cambium, phloem, sapwood and heartwood. Different organisms and fungi aid decomposition and colonize throughout decomposition stages (Siitonen 2001).

After severe disturbance, woody debris provides organisms with safe shelter and allows normal function progression by forming shaded microsites (Harmon et al. 1986). In Australia, fallen logs provided important habitat routes for ants in harsh mid-summer microclimates of low humidity and high surface soil temperature. Ground logs supply ants with an above ground pathway where foraging can continue despite harsh external climatic factors (Brennan et al. 2005).

Erosion can occur naturally through environmental causes or can have anthropogenic causes that are often accelerated and more detrimental (Whisenant 2005). In mining it is often most cost effective to construct steep slopes for reclamation (Kapolka and Dollhopf 2001). These steep slopes can lead to erosion when the force of impact by a raindrop exceeds the soil particle's ability to resist detachment. This force often results in formation of definable channels or rills down the hill slope. With prolonged time, rills can widen and develop into gullies (Whisenant 2005). Addition of rooted vegetation, litter and woody debris can decrease runoff and erosion severity by increasing surface stability and obstructing water movement on the soil surface (Stevens 1997, Whisenant 2005). Woody debris creates protective microsites that can prevent seeds and seedlings from being buried under sediment during hill slope erosion (Harmon et al. 1986). Seed and seedling growth may further be aided due to increased soil water content in areas shaded by dead logs (Harmon et al. 1986).

Woody debris is an important seedbed in forest ecosystems (Harmon et al. 1986), providing elevated safe sites where seedlings can lodge and establish without being buried by sediment and litter (Christy and Mack 1984). In a 50 year study in a Swedish boreal forest, > 65% of new spruce saplings established on or in connection with coarse woody debris (Hofgaard 1993). In a United States old growth forest, 98% of *Tsuga heterophylla* (Sarg.) (western hemlock) seedlings established on coarse woody debris that covered 6% of the forest floor (Christy and Mack 1984). Plant establishment most often occurs on highly decayed logs elevated above the forest floor. Such logs are beneficial since they provide elevated safe sites, are shedding litter, and the softened sapwood contains nutrients allowing access for root systems (Christy and Mack 1984).

Woody debris may help increase forest ecosystem productivity. In a comparison study, virgin forests produced taller trees and were thus more productive than managed forests. This was accredited to higher density of coarse woody debris in virgin forests (Debeljak 2006). In another study a positive correlation was found between forest density of coarse woody debris with forest productivity measured by living stand volume (Siitonen 2001).

11. ECOLOGICAL IMPACT OF WOODY DEBRIS ON SOIL PROPERTIES

Deficiency caused by lack of a major nutrient or obstruction in nutrient cycling can be a major limiting factor in reclamation (Palmer 1992). Adding woody debris to an ecosystem can aid nutrient availability. Although decaying wood can initially act as a nutrient sink, due to its low nutrient content and slow decomposition rate, woody debris is beneficial in the long term due to its high organic content and long term release of nutrients (Harmon et al. 1986).

In areas of disturbance, tree and fungi growth are inhibited by lack of nitrogen (Hicks et al. 2003). Woody debris is important for nitrogen fixation (Harmon et al. 1986, Pyle and Brown 1999, Zhou et al. 2007) with its organic material supplying an important source of ammonium for nitrification (Palmer 1992). Nitrogen fixing bacteria have been isolated on forest woody debris, with anaerobic and micro-aerophilic bacteria thought to be involved (Brunner and Kimmins 2003). In the first six years of decay, a freshly fallen log produces highest nitrogen fixation rates occurring first on bark, followed by sapwood, and then hardwood layers (Hicks et al. 2003). However, it can take several years for a newly fallen log to become completely colonized by nitrogen fixing bacteria (Harmon et al. 1986).

Brunner and Kimmins (2003) analyzed nitrogenase activity on coarse woody debris in forests. Nitrogenase is an enzyme used by all nitrogen fixing organisms. Nitrogenase activity was found on logs in all decay classes, with highest rates on logs in classes 3 and 4. Variability was large within and between logs of the same substrate and activity positively correlated with water content.

Decaying logs often increase in nutrient content during decomposition (Harmon et al. 1986) and nutrient immobilization can be common in decaying wood (Zimmerman et al. 1995). Decaying logs acquire increased nutrients from rainfall and throughfall, nitrogen fixation (Harmon et al. 1986) and nutrient translocation, especially phosphorus, from soil to logs by mycelial cord forming decomposing fungi (Wells and Boddy 1990). Nutrient immobilization has been found in Puerto Rico forest plots with hurricane damage. When comparing plots where woody debris was maintained and where woody debris and litter were experimentally removed, plots with removed woody debris had increased available soil nitrogen and higher above ground productivity. This is attributed to microorganisms using plant available nitrogen as a fuel source to decompose organic matter, thus immobilizing nitrogen in woody detritus (Zimmerman et al. 1995).

Undisturbed forestry plots have shown nutrient immobilization in woody debris. In northern New York, total Kjeldahl nitrogen and total phosphorus in woody debris increased with mass loss over three years of decay (Sinsabaugh et al. 1993). In southwest Alberta, nitrogen and phosphorus release was compared in pine, spruce and fir logs. After 14 years, pine logs gained nitrogen, spruce logs released nitrogen and fir logs released 30% of their nitrogen. All logs gained phosphorus, with fir logs acquiring almost four times their initial concentration. The lower initial substrate concentrations of nitrogen and phosphorus, the more nutrients were translocated to decomposing logs (Laiho and Prescott 1999).

Although these studies suggest woody debris inputs have initial negative effects, woody debris maintenance may have long term benefits due to nutrient preservation (Miller and Lodge 1997) and protection from leaching (Harmon et al. 1986, Carlyle et al. 1998). Woody residue helps prevent nitrogen and phosphorus leaching from sandy soils, low in organic matter and nutrients (Carlyle et al. 1998). Nutrients held by woody debris are retained in the ecosystem and slowly released (Harmon et al. 1986). As material is exhausted, microbial populations decline and nitrogen becomes available to plants (Zimmerman et al. 1995).

Saprotrophic fungi are primarily responsible for decomposition of woody plant material, which contains 80% of the global carbon pool (Lindahl et al. 2002). Saprotrophic fungi obtain carbon and energy directly by decomposing organic matter (Hobbie et al. 1999). Low molecular weight compounds, such as monosaccharides and amino acids, are utilized first. Polymeric compounds, such as cellulose and chitin, require enzymatic degradation and are slower to decompose and assimilate into fungal matter (Lindahl and Olsson 2004). Last and hardest to decompose are polyphenolic compounds, which result from fungal mediated lignin oxidation (Lindahl and Olsson 2004). White rot fungi and some mycorrhizal fungi can degrade polyphenolic compounds with enzymes mainly produced when nutrients are limited (Lindahl et al. 2002).

Woody debris and foliage are deposited on the soil as discrete units (Lindahl and Olsson 2004). If insufficient nitrogen and phosphorus are available for saprotrophic fungi to degrade woody debris, nutrients may be translocated from soil to woody material (Wells and Boddy 1990, Lindahl et al. 2002) or from adjacent areas of higher nutrient availability (Lindahl and Olsson 2004). Most fungi are composed of hypae, or a continuous hyphal network called mycelium, which can extend long distances (Lindahl and Olsson 2004). Fungi use these extensions to transport water, carbohydrates and nutrients (Lindahl et al. 2002) from high to low areas of resource availability (Laiho and Prescott 1999, Lindahl and Olsson 2004) to overcome heterogeneity in their environment (Lindahl et al. 2002, Lindahl and Olsson 2004). In such a system, one section of the mycelium can affect distant sections and performance of one hyphal tip may depend on nutritional resources available to the entire mycelium (Lindahl and Olsson 2004).

Instead of releasing acquired nutrients to soil solution during decomposition, fungi may translocate nutrients to recently colonized material, in which cellulose concentration is high and nutrient availability is low. In such instances, mineralization is rare (Lindahl et al. 2002). In an experiment where tracer isotope ^{15}nitrogen was applied to field plots, only 15% was assimilated by plants. The majority was found in non-root organic matter, seemingly incorporated into fungal mycelium (Lindahl et al. 2002). Bacteria and some microfungi cannot transport nutrients and thus conform to traditional models of mineralization where carbon sources are decomposed and inorganic nutrients are released to soil solution.

Organic matter supplied by woody debris helps in formation of mycorrhizal fungi and woody debris may help sustain mycorrhizal fungi diversity after disturbance (Vogt et al. 1995). Mycorrhizal fungi form a mutualistic relationship between vascular plants and fungi, improving root ability to uptake water and nutrients (Harmon et al. 1986, Dahlberg 2001). In boreal forest ecosystems, inorganic nutrients can be limited and plants must compete with microorganisms to obtain nutrients (Lindahl et al. 2002). Ectomycorrhizae and arbuscular mycorrhizae can improve plant survival by accessing soil nitrogen in organic forms of amino acids, amino sugars, peptides, proteins and chitin (Lindahl et al. 2002, Schimel and Bennett 2004). This added resource aids plants when nitrogen availability is low (Hobbie et al. 1999). Mycorrhizal fungi can play a direct role in decomposition and assimilation of organic nutrients (Schimel and Bennett 2004). These relationships can increase success of individual plants and reclamation success (Allen and Friese 1992). Mycorrhizal associations may enhance establishment of mycotrophic grasses and shrubs over non-mycotrophic weeds (Palmer 1992). Ectomycorrhizae are common in coniferous tree species (Vogt et al. 1995) and in other trees important to reclamation (Allen and Friese 1992).

Vogt et al. (1995) created experimental tree gaps to simulate disturbance. All predisturbance woody debris was left on site and root biomass and mycorrhizal diversity were analyzed. Six months after simulated disturbance, root biomass greatly decreased. Mycorrhizal fungi were no longer present in mineral soil, but were sustained best in live tree skirts (sloughed bark fragments found around a tree bole base) and highly decayed woody debris. Coniferous plant species utilized woody debris as a rooting matrix to a higher extent than understory species which rarely rooted in woody debris. Woody debris may serve different functions depending on location and decomposition stage (Vogt et al. 1995).

Competition for nutrients can occur between ectomycorrhizal and saprotrophic fungi (Lindahl et al. 2002). In a study conducted by Lindahl et al. (1999), mycelia of saprotrophic fungi *Hypholoma fasciculare* (Fr.) Kumm growing from wood blocks, confronted mycelia from ectomycorrhizal fungi growing with seedlings of *Pinus sylvestris* L. (Scots pine). Upon confrontation, tracer isotope ^{32}phosphorus was added to the saprotrophic mycelium. Over a 29 day period, 12% of ^{32}phosphorus translocated from saprotrophic mycelium to ectomycorrhizae and into plant roots. Ectomycorrhizae appeared to slow saprotrophic fungi growth and in some instances cause senesce (Lindahl et al. 2002). In a field study where mycorrhizae were experimentally excluded, decomposition rates increased, indicating a competitive interaction (Gadgil and Gadgil 1971).

Nutrient abundance of the source substrate of saprotrophic fungi can affect competitive interactions between saprotrophic and mycorrhizal fungi (Lindahl et al. 2001, Lindahl and Olsson 2004). Lindahl et al. (2001), performed a study similarly to Lindahl et al. (1999), except with saprotrophic fungi growing from either large (1.6 cm^3) or small (0.44 cm^3) wood blocks. Although ^{32}phosphorus was transferred in both directions between saprotrophic and mycorrhizal fungi, competitive ability was largely dependent on block size. Mycelium of decomposing fungi grown from large blocks captured a greater proportion of ^{32}phosphorus than mycelium of mycorrhizal fungi, whereas the reverse was true for decomposing fungi grown from small blocks. Saprotrophic fungi grown from larger blocks had higher extension rates and more vigorous growth. This study showed saprotrophic fungi can successfully compete against mycorrhizal fungi if a sufficient supply of energy and nutrients are available (Lindahl et al. 2001).

Competitive ability of saprotrophic mycelium depends on rate of nutrient uptake by hypae, quality of substrate resources, and biomass and activity of fungal mycelia (Lindahl and Olsson 2004). Therefore, as woody debris is depleted in highly assimilable nutrients and becomes mainly composed of recalcitrant complexes, it decreases strength. As strength decreases, competitive ability of decomposing fungi decreases (Lindahl and Olsson 2004). In a study by Wells and Boddy (1990), wood blocks in different stages of decay were inoculated with wood decomposing fungi *Phanerochaete velutina* (DC.) P. Karst. or *Phallus impudicus* L. Decay stage of the wood block was negatively correlated to amount of fungal mycelium, suggesting decomposing fungi growing from highly decayed wood devoid of assimilable nutrients will have a low competitive ability.

The quality of root substrate for mycorrhizal fungi can influence competitive ability. A plant with a high demand for nitrogen or phosphorus, but low availability, may provide more photosynthetically derived carbohydrates to the roots. This could improve competitive ability of the mycorrhizae to allow translocation of needed nutrients to the host plant (Lindahl and Olsson 2004). Mycorrhizal fungi may be able to manipulate their source substrate, but the extent is uncertain (Lindahl and Olsson 2004).

Interference competition may occur between microorganisms (Lindahl and Olsson 2004). Such competition is for territory rather than nutrients and results in reduced biomass for one or both competitors (Lindahl and Olsson 2004). Jayasinghe and Parkinson (2008) analyzed the community size and species richness of actinomycetes on the forest floor of temperate aspen, poplar and lodgepole pine forests in Alberta, Canada. The most abundant actinomycete was

Streptomyces, which can act as an antagonist to wood decomposing fungi. Slow growing decomposing fungi experience a greater antagonistic effect from *Streptomyces* than fast growing decomposing fungi.

Microbial biomass may be a major source of soil phosphorus and nitrogen for plants and microorganisms (Lindahl et al. 2002). Phosphorus and nitrogen concentrations are higher in fungal tissue than plant tissue. Chitin is a constituent of fungi cell walls and contains nitrogen. In boreal forest LFH horizons, 15 to 20% of nitrogen and 18% of organic phosphorus was found in living and dead fungal biomass. Fungi generally have a high turnover rate with a lifespan of a few weeks. Disturbance can cause mass mycelial senescence leading to localized increases in bacteria and microfungi, which will mineralize nutrients contained in fungal biomass and eventually release them to soil solution (Lindahl et al. 2002).

Lindahl et al. (2007), analyzed carbon nitrogen ratios (C:N) and fungal community composition of different horizons in the LFH layer of a boreal forest. C:N decreased in the fresh upper litter layers (L horizon) until fragmented litter (F horizon) was reached. From there, C:N increased significantly down to the humus layer (H horizon). ^{15}Nitrogen concentration was constant in the litter layers, but increased with soil depth from fragmented litter. Fungal community composition changed from a community dominated by saprotrophic fungi in the L horizon to a community dominated by mycorrhizal fungi from the F horizon. This shift in community composition is thought to occur after 3 to 5 years of decomposition. C:N in the upper litter layer decreased since saprotrophic fungi removed carbon by respiration and retained nitrogen in their biomass. The fragmented litter and humus layers increased in C:N since plant roots selectively remove nitrogen with the aid of mycorrhizal fungi (Lindahl et al. 2007).

Water leaching through woody debris can greatly influence soil chemistry (Hafner et al. 2005, Kuehne et al. 2008). Hafner et al. (2005) compared woody debris leachate to litter leachate and throughfall in a mixed wood forest in New York State. Woody debris leachate contributed highest concentrations of dissolved organic carbon, organic nitrogen and organic sulphur to soil solution. Woody debris leachate provided higher concentrations of potassium, calcium and magnesium compared to litter leachate. Woody debris and litter leachate contained lower concentrations of ammonium than throughfall. Of overall dissolved organic matter, dissolved organic carbon contributed the highest concentration, which could aid soil processes by providing labile carbon for soil microorganisms and aiding soil development. Dissolved organic carbon was positively correlated with cation concentration suggesting complexation, and supporting the importance of woody debris in controlling cation transport and availability. Since only a few fallen logs were present in this study, results applied to the microsite scale under woody debris. However, results are assumed to hold true at the ecosystem scale if many fallen logs are present (Hafner et al. 2005).

Kuehne et al. (2008) compared coarse woody debris in different decay classes to throughfall in a *Fagus sylvatica* L. (European beech) stand in Germany. Coarse woody debris leachate was significantly higher in dissolved organic carbon, dissolved organic nitrogen, nitrate, phosphorus, potassium, calcium, magnesium and C:N than throughfall. No differences were found in dissolved inorganic carbon and ammonium. Phosphorus and potassium were highest in leachate from freshly fallen logs and generally decreased as wood decayed (Kuehne et al. 2008). Runoff collected near dead wood hedges built with fresh woody debris was high in phosphorus. This can be a problem if soil is compacted and infiltration hindered, since phosphorus rich runoff can cause eutrophication of surface water (Auerswald and Weigand 1996). Krankina et al. (1999) attributed high concentrations of phosphorus in fresh woody debris leachate to the presence of bark, which is richer in nutrients than wood (Brown et al. 1995). During early stages of decay, more phosphorus is lost from the bark than acquired in wood. During early stages of decay, nitrogen remained relatively constant but phosphorus and potassium concentrations decrease. After decay class III, nitrogen and phosphorus concentrations within logs increased and potassium concentrations remained constant (Krankina et al. 1999).

12. RESEARCH OBJECTIVES

The overall objective of this research was to determine whether placing woody debris over cover soil will aid reclamation of severely degraded land by enhancing vegetation establishment and soil physical, chemical and biological properties. Two reclaimed sites were analyzed, a four year old and a two year old. The four year old site was constructed with a peat mineral mix cover (peat) to compare treatments of *Populus tremuloides* mixed wood woody debris to treatments with no woody debris and a cover crop of *Hordeum vulgare* L. (common barley). The two year old site was constructed using upland surface soil (LFH) and peat covers to compare treatments of *Populus tremuloides* mixed wood woody debris, *Picea mariana* woody debris and no woody debris.

Specific research objectives were as follows.

- Determine if woody debris affects vegetation canopy cover and biovolume, species composition and richness, and woody plant abundance.
- Determine if woody debris affects survival and height of planted saplings (only four year old site).
- Determine if woody debris presence and size affects surface soil temperature and water (only on two year old site).
- Determine if woody debris presence and size affects plant available nutrients, total carbon, total organic carbon, total nitrogen, carbon nitrogen ratio, sodium absorption ratio, electrical conductivity, pH, and soil particle size.
- Determine if woody debris presence and size affects microbial biomass carbon.
- Determine if woody debris affects mycorrhizal biomass.

13. LITERATURE CITED

Alberta Department of Energy. 2005. Government of Alberta: mineable oil sands strategy. Government of Alberta. Edmonton, Alberta. 9 pp.

Alberta Department of Energy. 2006. Alberta's oil sands 2005. Government of Alberta. Edmonton, Alberta. 4 pp.

Allen, M.F. and C.F. Friese. 1992. Mycorrhizae and reclamation success: importance and measurement. Proceedings of a Symposium. April 23-26, 1990. United States Department of Agriculture. Charleston, West Virginia. Pp. 17-25.

Auerswald, K. and S. Weigand. 1996. Ecological impact of dead-wood hedges; release of dissolved phosphorus and organic matter into runoff. Ecological Engineering 7:183-189.

Bonan, G.B. and H.H. Shugart. 1989. Environment factors and ecological processes in boreal forests. Annual Review of Ecology and Systematics 20:1-28.

Boddy, L. 2001. Fungal community ecology and wood decomposition processes in angiosperms: from standing tree to complete decay of coarse woody debris. Ecological Bulletins 49:43-56.

Brennan, K.E.C., O.G. Nichols and J.D. Majer. 2005. Innovative techniques for promoting faunal return to rehabilitated sites following mining. Australian Centre for Minerals Extension and Research, Brisbane and Minerals and Energy Research Institute of Western Australia (MERIWA Report 248). Perth, Australia. 123 pp.

Brown, S., J. Mo, J.K. McPherson and D.T. Bell. 1995. Decomposition of woody debris in Western Australian forests. Canadian Journal of Forest Research 26:954-966.

Brunner, A. and J.P. Kimmins. 2003. Nitrogen fixation in coarse woody debris of *Thuja plicata* and *Tsuga heterophylla* forests on northern Vancouver Island. Canadian Journal of Forest Research 33:1670-1682.

Carlyle, J.C., M.W. Bligh and E.K. Sadanandan Nambiar. 1998. Woody residue management to reduce nitrogen and phosphorus leaching from sand soil after clear-felling *Pinus radiate* plantations. Canadian Journal of Forest Research 28:1222-1232.

Christy, E.J. and R.N. Mack. 1984. Variation in demography of juvenile *Tsuga heterophylla* across the substratum mosaic. Journal of Ecology 72(1):75-91.

Cook, J.E. 1996. Implications of modern successional theory for habitat typing: a review. Forest Science 42(1):67-75.

Dahlberg, A. 2001. Community ecology of ectomycorrhizal fungi: an advancing interdisciplinary field. New Phytologist 150(3):555-562.

Debeljak, M. 2006. Coarse woody debris in virgin and managed forest. Ecological Indicators 6:733-742.

Deming, D. 2000. Oil: are we running out? Second Wallace E. Pratt Memorial Conference. San Diego, California. 18 pp.

DePuit, E.J. 1984. Potential topsoiling strategies for enhancement of vegetation diversity on mined lands. Minerals and the Environment 6:115-120.

Gadgil, R.L. and P.D. Gadgil. 1971. Mycorrhiza and litter decomposition. Nature 233:133.

Government of Alberta. 2009. Environmental management of Alberta's oil sands. Edmonton, Alberta. 24 pp.

Graham, S.A. 1925. The felled tree trunk as an ecological unit. Ecology 6(4):397-411.

Haeussler, S., L. Bedford, A. Leduc, Y. Bergeron and J.M. Kranabetter. 2002. Silvicultural disturbance severity and plant communities of the southern Canadian boreal forest. Silva Fennica 36(1):307-327.

Hafner, S.D., P.M. Groffman and M.J. Mitchell. 2005. Leaching of dissolved organic carbon, dissolved organic nitrogen, and other solutes from coarse woody debris and litter in a mixed forest in New York state. Biogeochemistry 74:257-282.

Harmon, M.E., J.F. Franklin, F.J. Swanson, P. Sollins, S.V. Gregory, J.D. Lattin, N.H. Anderson, S.P. Cline, N.G. Aumen, J.R.Sedell, G.W. LienKaemper, K. Cromack Jr. and K.W. Cummins. 1986. Ecology of coarse woody debris in temperate ecosystems. Advances in Ecological Research 15:133-302.

Herrick, J.E., G.E. Shuman and A. Rango. 2006. Monitoring ecological processes for restoration projects. Journal for Nature Conservation 14:161-171.

Hicks, W.T., M.E. Harmon and D.D. Myrold. 2003. Substrate controls on nitrogen fixation and respiration in woody debris from the Pacific Northwest, USA. Forest Ecology and Management 176:25-35.

Hobbie, E.A.. S.A. Macko and H.H. Shugart. 1999. Insights into nitrogen and carbon dynamics of ectomycorrhizal and saprotrophic fungi from isotopic evidence. Oecologia 118:353-360.

Hofgaard, A. 1993. 50 years of change in a Swedish boreal old-growth *Picea abies* forest. Journal of Vegetation Science 4(6):773-782.

Jayasinghe, B.A.T.D. and D. Parkinson. 2008. Actinomycetes as antagonists of litter decomposition fungi. Applied Soil Ecology 38:109-118.

Kapolka, N.M. and D.J. Dollhopf. 2001. Effect of slope gradient and plant growth on soil loss on reconstructed steep slopes. International Journal of Surface Mining, Reclamation, and Environment 15(2):86-99.

Knoepp, J.D., D.C. Coleman, D.A. Crossley Jr. and J.S. Clark. 2000. Biological indices of soil quality: an ecosystem case study of their use. Forest Ecology and Management 138:357-368.

Krankina, O.N., M.E. Harmon and A.V. Griazkin. 1999. Nutrient stores and dynamic of woody detritus in a boreal forest: modeling potential implications at the stand level. Canadian Journal of Forest Research 29:20-32.

Kuehne, C., C. Donath, S.I. Muller-Using and N. Bartsch. 2008. Nutrient fluxes via leaching from coarse woody debris in a *Fagus sylvatica* forest in the Solling Mountains, Germany. Canadian Journal of Forest Research 38:2405-2413.

Laiho, R. and C.E. Prescott. 1999. The contribution of coarse woody debris to carbon, nitrogen, and phosphorus cycles in three Rocky Mountain coniferous forests. Canadian Journal of Forest Research 29:1592-1603.

Laiho, R. and C.E. Prescott. 2004. Decay and nutrient dynamics of coarse woody debris in northern coniferous forests: a synthesis. Canadian Journal of Forest Research 34:763-777.

Lindahl, B.D., K. Ihrmark, J. Boberg, S.E. Trumbore, P. Hogberg, J. Stenlid and R.D. Finlay. 2007. Spatial separation of litter decomposition and mycorrhizal nitrogen uptake in a boreal forest. New Phytologist 173:611-620.

Lindahl, B.D. and S. Olsson. 2004. Fungal translocation – creating and responding to environmental heterogeneity. Mycologist 18(2):79-88.

Lindahl, B., J. Stenlid and R. Finlay. 2001. Effects of resource availability on mycelial interactions and ^{32}P transfer between saprotrophic and an Ectomycorrhizal fungus in soil microcosms. FEMS Microbiology Ecology 38:43-52.

Lindahl, B., J. Stenlid, S. Olsson, and R. Finlay. 1999. Translocation of ^{32}P between interacting mycelia of a wood decomposing fungus and ectomycorrhizal fungi in microcosm systems. New Phytologist 144:183-193.

Lindahl, B.D., A.F.S. Taylor and R.D. Finlay. 2002. Defining nutritional constraints on carbon cycling in boreal forests – towards a less ‘phytocentric’ perspective. Plant and Soil 242:123-135.

MacKenzie, D.D. and M.A. Naeth. 2007. Assisted natural recovery using a forest soil propagule bank in the Athabasca oil sands. Seeds: Biology, Development and Ecology. Pp. 374-382.

Miller, R.M. and D.J. Lodge. 1997. Five fungal responses to disturbance: agriculture and forestry. In: Esser K., P.A. Lemke, D.T. Wicklow. The Mycota. Berlin: Springer-Verlag. Pp. 65-48.

Molles Jr., M.C. 2002. Ecology: concepts and applications. McGraw-Hill Companies, Inc. New York, New York. Pp. 37-38.

National Energy Board. 2000. Canada’s oil sands: a supply and market outlook to 2015. An Energy Market Assessment. Calgary, Alberta. 121 pp.

Oil Sands Revegetation Reclamation Committee. 1998. Guidelines to reclamation to forest vegetation in the Athabasca Oil Sands Region. Fort McMurray, Alberta. 212 pp.

Palmer, J.P. 1992. Nutrient cycling: the key to reclamation success? Proceedings of a Symposium. April 23-26, 1990. United States Department of Agriculture. Charleston, West Virginia. Pp. 27-36.

Pickett, S.T.A. 1976. Succession: an evolutionary interpretation. The American Naturalist 110(971):107-119.

Powter, C.B. (Compiler), 2002. Glossary of reclamation and remediation terms used in Alberta. 7th Edition. Alberta Environment, Science and Standards Branch, Edmonton, Alberta. Pub. No. T/655; Report No. SSB/LM/02-1. 88 pp. ISBN 0-7785-2153-2 (Printed Edition) or ISBN: 0-7785-2156-7 (Online).

Purdy, B.G., S.E. Macdonald and V.J. Lieffers. 2005. Naturally saline boreal communities as models for reclamation of saline oil sands tailings. Restoration Ecology 13(4):667-677.

Pyle, C. and M.M. Brown. 1999. Heterogeneity of wood decay classes with hardwood logs. Forest Ecology and Management 144:253-259.

Renault, S., J.J. Zwiazek, M. Fung and S. Tuttle. 2000. Germination, growth and gas exchange of selected boreal forest seedlings in soil containing oil sands tailings. Environmental Pollution 107:357-365.

Ruiz-Jaen, M.C. and T.M. Aide. 2005. Restoration success: how is it being measured? Restoration Ecology 13(3):569-577.

Schimel, J.P. and J. Bennett. 2004. Nitrogen mineralization: challenges of a changing paradigm. Ecology 85(3):591-602.

SER (Society for Ecological Restoration International Science and Policy Working Group). 2004. The SER international primer on ecological restoration. Society for Ecological Restoration International. Tucson, Arizona. http://www.ser.org/content/ecological_restoration_primer.asp Accessed 1 November 2008.

Siitonen, J. 2001. Forest management, coarse woody debris and saproxylic organisms: Fennoscandian boreal forests as an example. Ecological Bulletins 49:11-41.

Singh, K. 2007. Approval: province of Alberta, environmental protection and enhancement act. R.S.A. 2000, c.E-12, as amended. Alberta Environment. Suncor Energy, Inc. Fort McMurray, Alberta. 105 pp.

Sinsabaugh, R.L., R.K. Antibus, A.E. Linkins, C.A. McClaugherty, L. Rayburn, D. Repert and T. Weiland. 1993. Wood decomposition: nitrogen and phosphorus dynamics in relation to extracellular enzyme activity. Ecology 74(5):1586-1593.

Sprugel, D.G. 1991. Disturbance, equilibrium, and environmental variability; what is 'natural' vegetation in a changing environment. Biological Conservation 58:1-18.

Ståhl, G., A. Ringvall and J. Fridman. 2001. Assessment of coarse woody debris - a methodological overview. Ecological Bulletins 49:57-70.

Stevens, V. 1997. The ecological role of coarse woody debris: an overview of the ecological importance of CWD in BC forests. Research Branch, British Columbia Ministry of Forests Working Paper 30. Victoria, British Columbia.

Thompson, J.N., O.J. Reichman, P.J. Morin, G.A. Polis, M.E. Power, R.W. Sterner, C.A. Couch, L. Gough, R. Holt, D.U. Hooper, F. Keesing, C.R. Lovell, B.T. Milne, M.C. Molles, D.W. Roberts and S.Y. Strauss. 2001. Frontiers of ecology. BioScience 51(1):15-24.

Vogt, K.A., D.J. Vogt, H. Asbjornsen and R.A. Dahlgren. 1995. Roots, nutrients and their relationship to spatial patterns. Plant and Soil 168-169(1):113-123.

Wells J.M. and L. Boddy. 1990. Woody decay, and phosphorus and fungal biomass allocation, in mycelial cord systems. New Phytologist 116:285-295.

Whisenant, S. 2005. 50 first steps in erosion control. Forest Restoration in Landscapes. Springer. New York, New York. Pp. 350-351.

Winter Sydnor, M.E. and E.F. Redente. 2002. Ecosystem restoration: reclamation of high-elevation, acidic mine waste with organic amendments and topsoil. Journal of Environmental Quality 31:1528-1537.

Woynillowicz, D., C. Severson-Baker and M. Raynolds. 2005. Oil sands fever: the environmental implications of Canada's oil sands rush. The Pembina Institute. Edmonton, Alberta. 86 pp.

Yan. E., X. Wang, and J. Huang. 2006. Concept and classification of coarse woody debris in forest ecosystems. Frontiers of Biology in China 1:76-84.

Zhou, L., L. Dai, H. Gu and L. Zhong. 2007. Review on the decomposition and influence factors of coarse woody debris in forest ecosystems. Journal of Forestry Research 18(1):48-54.

Zimmerman J.K., W.M. Pulliam, D.J. Lodge, V. Quinones-Orfila, N. Fetcher, S. Guzmán-Grajales, J.A. Parrotta, C.E. Asbury, L.R. Walker and R.B. Waide. 1995. Nitrogen immobilization by decomposing woody debris and the recovery of tropical wet forest from hurricane damage. Oikos 72:314-322.

Table 1.1 Classification of decay class for coarse woody debris logs.

	Decay Classes				
Characteristic	1	2	3	4	5
Structural integrity	Sound	Sapwood slightly rotting, heartwood sound	Sapwood missing, heartwood mostly sound	Heartwood decayed	Soft
Leaves	Present	Absent	Absent	Absent	Absent
Branches	All twigs present	Larger twigs present	Larger branches present	Branch stubs present	Absent
Bark	Present	Present	Often present	Often absent	Absent
Bole shape	Round	Round	Round	Round to oval	Oval to flat
Wood consistency	Solid	Solid	Semisolid	Partly soft	Fragmented powdery
Color of wood	Original color	Original color	Original color to faded	Original color to faded	Heavily faded
Invaded by roots	No	No	Sapwood area	Throughout	Throughout
Vegetation growing	No	Little vegetation growing	Few shrubs, seedlings and mosses	Shrubs, mosses and trees	Shrubs, mosses and trees
Indirect measure	Cambium still fresh, dies < 1 year	Cambium decayed, knife blade penetrates a few mm	Knife blade penetrates < 2 cm	Knife blade penetrates 2 to 5 cm	Knife blade penetrates all the way

Adapted from Yan et al. 2006.

CHAPTER II. EFFECT OF WOODY DEBRIS ON VEGETATION ESTABLISHMENT AND SOIL PROPERTIES ON A FOUR YEAR OLD RECLAIMED SITE IN THE ATHABASCA OIL SANDS REGION, ALBERTA, CANADA

1. INTRODUCTION

Boreal forests in the Athabasca Oil Sands Region of Alberta, Canada are impacted by severe anthropogenic disturbances from mining. Oil sands contain high concentrations of bitumen which are removed by mining or by in situ methods using wells and pipelines (Alberta Department of Energy 2006). Mining is preferred for shallow deposits in a 4,800 km^2 area, of which approximately 602 km^2 have been disturbed (Government of Alberta 2009). Once mining operations have been completed, oil sands industries are responsible for reclaiming land to self sustaining ecosystems with an equivalent capability to predisturbance ecosystems (Oil Sands Vegetation Reclamation Committee 1998).

Reclamation after mining includes topsoiling, or reapplication of salvaged soil to degraded land (DePuit 1984, Winter Sydnor and Redente 2002, MacKenzie and Naeth 2007). Topsoiling can increase soil organic matter, available nutrients, microorganisms, water holding capacity and above ground biomass (Winter Sydnor and Redente 2002) and can be a source of native seeds and propagules (DePuit 1984, MacKenzie and Naeth 2007). A commonly used topsoil is peat mineral mix; usually 1 m of organic peat with 0.4 m of underlying mineral soil (Oil Sands Revegetation Reclamation Committee 1998, Singh 2007) (hereafter referred to as peat). Peat is beneficial since it is readily available in northern Alberta and has high organic matter content (Fung and Macyk 2000). Once peat is spread, an annual cover crop of *Hordeum vulgare* L. (common barley) is planted. Barley controls erosion by providing above and below ground biomass (Oil Sands Revegetation Reclamation Committee 1998).

Large quantities of woody debris are collected during land clearing for mining. Woody debris is defined as all dead woody material in a forest ecosystem, including dead wood on the forest floor such as logs, fallen limbs, twigs and woody fruit; below ground dead roots and buried wood; and standing snags and stumps (Pyle and Brown 1999). Woody debris is also called logging waste, slash residue, forest residue or habitat logs (Brennan et al. 2005). The trees are sold as merchantable timber or treated as waste by burning or burying in large pits.

Few studies have assessed the benefits of using woody debris in reclamation of severely degraded land except to note its value in reducing soil erosion (Stevens 1997, Whisenant 2005). Several studies in forest ecosystems found woody debris provided habitat and shelter for various organisms (Graham 1925, Harmon et al. 1986, Siitonen 2001, Brennan et al. 2005, Debeljak 2006), increased microbial diversity (Harmon et al. 1986, Pyle and Brown 1999, Hicks et al. 2003), aided nutrient cycling (Harmon et al. 1986, Pyle and Brown 1999, Hicks et al. 2003, Hafner et al. 2005) and increased plant growth (Christy and Mack 1984, Hofgaard 1993) and productivity (Siitonen 2001, Debeljak 2006). Some studies found woody debris immobilized nutrients (Sinsabaugh et al. 1993, Zimmerman et al. 1995, Laiho and Prescott 1999), others suggested it helped preserve nutrients on site (Miller and Lodge 1997) and prevented excessive leaching (Harmon et al. 1986, Carlyle et al. 1998). Over time, woody debris decays and its nutrients are again available to plants (Harmon et al. 1986, Zimmerman et al. 1995). Due to the ecological value woody debris has in forest ecosystems, it might have similar positive effects in reclamation.

2. RESEARCH OBJECTIVES

This study aimed to determine if applying a heavy mixed cover of *Populus tremuloides* Michx. (trembling aspen) and *Picea glauca* (Moench) Voss (white spruce) woody debris over peat mineral mix topsoil enhanced reclamation after oil sands mining. Specific objectives were as follows.

- Determine effects of woody debris on vegetation canopy cover, composition and richness.
- Determine effects of woody debris on survival and height of planted saplings.
- Determine effects of woody debris on soil chemical and physical properties such as available nutrients, carbon nitrogen ratio (C:N), sodium absorption ratio (SAR), electrical conductivity (EC), pH, and particle size.
- Determine effects of woody debris on microbial properties such as soil microbial biomass carbon and mycorrhizal biomass.

3. METHODS

3.1 RESEARCH SITE DESCRIPTION

Research was conducted at Suncor Energy Inc., 24 km north of Fort McMurray, Alberta, Canada in the central mixed wood natural subregion of the boreal forest natural region (Natural Regions Committee 2006). The area typically has long cold winters and short warm summers with an average annual temperature of 0.7 ℃. Maximum temperatures typically occur in July at 23.2 ℃ and minimum temperatures occur in January at -24 ℃. Average annual precipitation is 455.5 mm, with 342.2 mm as rain and 155.8 cm as snow (Environment Canada 2003).

Topography of the central mixed wood natural subregion consists of large areas of upland forests, wetlands and rolling plains. Upland forests are generally composed of *Populus tremuloides* and *Picea glauca* mixed wood stands, however *Populus balsamifera* L. (balsam poplar) and *Pinus banksiana* Lamb. (jack pine) can also occur. Wetlands primarily consist of *Picea mariana* Mill. BSP. (black spruce) bogs and fens, commonly with *Salix* spp. (willow), *Ledum glandulosum* Nutt. (Labrador tea) and sedge species. Soils of upland stands are mainly Gray Luvisols with some Dystric and Eutric Brunisols. Bogs and fens have Organic soils predominantly of Mesisols. Gleying and Gleysols occur in some depressions (Natural Regions Committee 2006).

3.2 EXPERIMENTAL DESIGN, TREATMENTS AND PLOT ESTABLISHMENT

Plots were located along the slope of the steep bank north dump (Figure 2.1), a large mound of lean oil sand material that does not meet the bitumen grade necessary to be classified as ore (Singh 2007). In late winter 2004, the dump was covered with peat mineral mix at a depth of 26 cm. Shortly after, six plots were established in pairs. Each pair had a plot with heavy woody debris cover and an adjacent plot with no woody debris, seeded to a cover crop of barley (Figure 2.1). Plots were 80 m long, 15 to 30 m wide and ran up slope (Table 2.1).

Woody debris was collected in early May 2004, from a nearby, recently cleared upland *Populus tremuloides* and *Picea glauca* mixed wood forest. Merchantable logs were sold, leaving bent stems and branches of *Populus tremuloides* and smaller *Picea glauca* trees. Fresh woody debris with little or no sign of decay, was spread by backhoe with grapple device in mid May 2004. Original cover was greater than 80% but declined to 25 to 43% at the time of this study (Table 2.1).

In August 2005 20 *Populus tremuloides* and 20 *Picea glauca* saplings were planted (Table 2.1) in 4 rows of 10 running the slope length. Plots were aerially fertilized in July 2005 with 23.5 nitrogen: 25 phosphorus: 8 potassium at a rate of 300 kg ha^{-1}; and in August 2006 and 2007 with a 31.5:16:5 mix at 250 kg ha^{-1}.

3.3 VEGETATION ASSESSMENT

Vegetation assessments were conducted in July 2007. Three line transects were established vertically up the slope of each plot. On each transect, evenly spaced 1 m^2 quadrats were established. Number of quadrats per plot varied depending on results of a species area curve and ranged from 23 to 30. Within each quadrat, percent canopy cover of bare ground, rock, litter, woody debris, moss and vegetation was estimated. Covers were recorded at 0.5% intervals and covers < 0.5% were recorded as trace. Dead vegetation and bark fragments from woody debris were considered litter. Canopy levels were accounted for and sum of percentages could equal > 100%. Canopy cover of vegetation by species was estimated at all canopy levels. Only vegetation rooted in the quadrat and runners of *Fragaria virginiana* (Duchesne) (wild strawberry) that extended into the quadrat were included in canopy cover. Species nomenclature follows Moss (1994).

Planted saplings of *Populus tremuloides* and *Picea glauca* were assessed in July 2007 for presence, health and height. Presence was categorized as either visibly present or missing. Health was categorized as healthy, marginal, unhealthy or dead. Healthy saplings were completely green with no brown or yellow spots. Marginal saplings had < 25% brown and yellow spots. Unhealthy saplings had $\geq$ 25% yellow and brown or red spots. Dead saplings were completely brown or red. Height was measured in cm.

3.4 SOIL CHEMICAL AND PHYSICAL PROPERTIES

Three soil samples were randomly collected and composited from the mid slope section of each plot in August 2007 from a surface depth of 0 to 10 cm using a 5 cm diameter dutch auger. Samples were refrigerated (4 ℃) for two months before analyses were completed by ALS Laboratory Group in Edmonton, Alberta.

Hydrocarbons were removed before other analyses by gravimetric soxhlet extraction (American Public Health Association et al. 2000). Available nitrate (NO_3^-) was determined by extraction with 0.001 M $CaCl_2$, (Carter and Gregorich 2008). Available phosphorus and potassium were determined by modified Kelowna extraction (Qian et al. 1994). Available sulphate (SO_4) was determined by inductively coupled plasma - atomic emission spectrophotometry. Total and available sulphur are assumed to be the same for mineral soils from the prairies (Alberta Agriculture 1988). Total carbon and total nitrogen were determined by dry combustion (Nelson and Sommers 1996, Bremner 1996). Inorganic carbon was determined via CO_2 release (Loeppert and Suarez 1996). Total organic carbon was calculated by subtracting total inorganic carbon from total carbon. C:N ratio was determined by calculating the ratio of total carbon to total nitrogen.

Electrical conductivity (EC), pH and sodium adsorption ratio (SAR) were determined from saturated paste extracts (Carter and Gregorich 2008). Soils with EC > 4 dS m^{-1} are considered saline. Soils with SAR > 13 are considered sodic. Sand, silt and clay were determined by the hydrometer method after treatment with calgon (Carter and Gregorich 2008). Two samples had organic matter too high for the hydrometer method and were treated with 1 N HCl to remove carbonates and H_2O_2 to oxidize organic matter (Kalra and Maynard 1991).

3.5 MICROBIAL AND MYCORRHIZAL BIOMASS

In August 2007, the roots and rhizosphere of six plant species were collected. Species included: *Achillea millefolium* (L.) (common yarrow), *Agrostis scabra* (Willd.) (tickle grass), *Calamagrostis canadensis* (Michx.) Beauv. (marsh reed grass), *Epilobium angustifolium* (L.) (fire weed), *Equisetum arvense* (L.) (horse tail) and *Fragaria virginiana*. Samples were collected by carefully extracting plants from soil with a shovel and collecting roots and root held soil in a plastic bag. Only roots were collected for *Epilobium angustifolium* since this species has a tap root that did not hold soil. Samples were double bagged, placed directly on dry ice (-78 ℃), transported on dry ice and stored in a freezer (-20 ℃) until analyses were conducted between April and May 2008. Soil rhizosphere samples were analyzed for microbial biomass carbon by chloroform fumigation extraction (Vance et al. 1987). Root samples were analyzed for mycorrhizal biomass, measured by glucosamine according to modified procedures from Nilsson and Bjurman (1998), Appuhn et al. (2004) and Appuhn and Joergensen (2006).

3.6 STATISTICAL ANALYSES

Vegetation trace values were set to 0.1% to account for presence. Since woody debris was fresh and plant roots cannot utilize it as a rooting substrate, the proportion of ground available for rooting (available ground) was calculated by subtracting percent woody debris and rock cover from the total area. Vegetation cover per available ground was then calculated. For canopy cover by species, each species was separated into plant groups based on morphology, origin and life history stage (Appendix B.1). Plant group classifications follow Moss (1994). Unknown plants were included in morphology and total groupings. Plants not identified to species (*Carex* and *Salix*) were excluded from plant origin and species richness analyses. Proportion of saplings in each health rating was calculated since not all plots had the same number of saplings planted. Ratings of missing and dead were combined since missing saplings were assumed dead.

Only *Fragaria virginiana* had sufficient rhizosphere soil for three distinct replicates for microbial biomass carbon analysis. For the others, soil samples were composited and three replicates were removed for analysis. A similar problem occurred with root for glucosamine analysis. Enough samples were collected to have a replicate from each plot for *Achillea millefolium*, *Epilobium angustifolium* and *Fragaria virginiana*. Three replicates of each treatment were not collected for *Agrostis scabra*, *Calamagrostis canadensis* and *Equisetum arvense*, so samples were comprised from treatments with more than the required amount of roots.

SigmaStat 11.0 statistical software was used to compare woody debris and non woody debris treatments. A t-test statistic was used to analyze differences in canopy cover parameters, sapling height and soil chemical and physical parameters. If data did not have equal variance, the non parametric Mann Whitney rank sum test was used. A two way ANOVA was used to analyze differences between treatments and plant species for sapling presence, health ratings, microbial biomass carbon and glucosamine content. A post hoc Tukey test was used to locate the significant differences. A linear regression ANOVA was conducted to determine the relationship between vegetation cover per available ground and woody debris cover. Significance was determined at $p \le 0.1$ to increase power due to a small sample size ($n = 3$) (Zar 1999).

4. RESULTS AND DISCUSSION

4.1 EFFECT OF WOODY DEBRIS ON VEGETATION COVER

Vegetation canopy cover was significantly higher without woody debris than with woody debris ($p = 0.005$) (Table 2.2). Vegetation cover per available ground was not significantly different between treatments (Table 2.2) and increased as woody debris cover increased ($R^2 = 0.2151$; $p > 0.001$) (Figure 2.2).

Non woody debris treatments had significantly more litter cover than woody debris treatments ($p = 0.051$) (Table 2.2). During summer 2007, when vegetation assessments were conducted, barley had died and was contributing large amounts of litter to non woody debris sites. Woody debris sites had large amounts of litter since bark fragments were considered litter cover.

4.2 EFFECT OF WOODY DEBRIS ON VEGETATION COMPOSITION AND RICHNESS

Although non woody debris treatments had significantly more vegetation cover than woody debris treatments ($p = 0.007$) (Table 2.3), 58.8% was introduced species, with 48% *Sonchus arvensis* L. (perennial sow thistle) (Table 2.4). On woody debris treatments 21.6% of vegetation was introduced species and 14.1% was *Sonchus arvensis*. Abundance of *Sonchus arvensis* explains why non woody debris treatments had higher forb and perennial species cover ($p = 0.009$, $p = 0.002$) (Table 2.3). The most abundant species on woody debris treatments was *Epilobium angustifolium* L. (fireweed) which comprised 40.2% of vegetation cover (Table 2.4). Species with the highest cover on non woody debris treatments were *Sonchus arvensis* (58.8%), *Epilobium angustifolium* (15.4%), *Erigeron canadensis* L. (horseweed) (9.2%), *Calamagrostis canadensis* (Michx.) Beauv.

(marsh reed grass) (6.4%) and *Hordeum jubatum* L. (foxtail barley) (5.9%), comprising 95.7% of vegetation cover. Species with the greatest canopy cover on woody debris treatments were *Epilobium angustifolium* (40.2%), *Sonchus arvensis* (14.1%), *Hordeum jubatum* (10.5%), *Equisetum arvense* (8.8%) and *Erigeron canadensis* (5.3%), comprising 78.9% of vegetation (Table 2.4).

Woody debris treatments had higher species richness than non woody debris treatments, but differences were not significant (Table 2.2 and 2.5). Woody debris treatments had 42 different species, four of which were introduced (Tables 2.5). Treatments without woody debris had 35 species, six of which were introduced. The higher species richness of woody debris treatments could be due to the greater cover of *Sonchus arvensis*, a highly competitive noxious weed, on non woody debris plots (p = 0.019) (Table 2.4). Such dominance can reduce species richness. The high cover of woody debris disrupted the spread of *Sonchus arvensis* and created microsites where other species could establish. In competition for survival, the influence one species has on another increases as its population size increases; microsites, or safe sites, allow greater opportunity for cohabitation (Harper et al. 1961). The regeneration niche theory introduced by Grubb (1977) suggests different plant species need specific environmental conditions. Reclaimed sites in the oil sands are mainly flat and homogeneous leaving seedlings exposed to climatic and biotic stressors. Adding woody debris increases the variety of niches present and thus can increase species richness.

4.3 EFFECT OF WOODY DEBRIS ON PLANTED SAPLINGS

Plots with woody debris had significantly more planted saplings alive (p = 0.003) and classified as healthy (p = 0.005) (Table 2.6 and 2.7). Non woody debris treatment had significantly more dead saplings (p = 0.004). Most saplings on woody debris treatments were healthy, whereas most on non woody debris treatments were dead (Figure 2.3). *Picea glauca* saplings were significantly taller in woody debris treatments (p = 0.039), and *Populus tremuloides* saplings showed no significant difference between treatments (Table 2.8).

Although no other studies have analyzed how woody debris affects planted saplings on highly disturbed landscapes, some similar studies exist. Beach and

Halpern (2001) found a positive association between *Alnus rubra* Bong. (red alder) regeneration and coarse woody debris. Grey and Spies (1997) analyzed forest tree gaps and found a greater number of *Pseudotsuga menziesii* (Mirb.) Franco (Douglas fir) and *Tsuga heterophylla* (Raf.) Sarg. (western hemlock) saplings growing near fallen logs. Relationships between sapling survival and woody debris might be even more important on highly disturbed landscapes and areas undergoing early or primary succession. Such areas are often subjected to stressful conditions where high temperatures and desiccation can be problematic (Jumpponen et al. 1999). Woody debris shades surrounding areas and can reduce soil surface temperatures and evaporation which can aid sapling survival.

4.4 EFFECT OF WOODY DEBRIS ON SOIL CHEMICAL PARAMETERS

Treatments without woody debris had significantly more total carbon (p = 0.008), total organic carbon (p = 0.008) and total nitrogen (p = 0.040) than those with woody debris, however there were no differences in C:N (Table 2.9). No significant treatment differences occurred for SAR and EC and values were low enough to class soils as good according to Alberta Tier 1 guidelines (Alberta Environmental Protection 1994). Both soils had a neutral pH (Table 2.9).

Non woody debris treatments had more soil available nitrate (p = 0.007) (Table 2.9), which could indicate nutrient immobilization. Some studies found forest floors with woody debris had low soil nitrogen (Zimmerman et al. 1995, Kayahara et al. 1996). Other studies showed woody debris increasing in nitrogen content over time (Harmon et al. 1986, Sinsabaugh et al. 1993, Laiho and Prescott 1999). Woody debris can acquire nitrogen by rainfall and throughfall, nitrogen fixation (Harmon et al. 1986, Brunner and Kimmins 2003) and translocation of nutrients from soil by mycelial cord forming saprotrophic fungi (Wells and Boddy 1990).

Several studies found similar immobilization of phosphorus (Wells and Boddy 1990, Sinsabaugh et al. 1993, Kayahara et al. 1996, Laiho and Prescott 1999). Soil in woody debris treatments in this study had more available phosphorus than treatments without woody debris (p = 0.089) (Table 2.9). The difference can be attributed to leachate from fresh woody debris, which is high in phosphorus (Auerswald and Weigand 1996, Krankina et al. 1999, Kuehne et al 2008).

Krankina et al. (1999) attributed this to nutrient rich bark. During early stages of decay, more phosphorus is leached from the bark than is immobilized in the wood. Decomposition of the phloem can result in rapid loss of 10 to 20% of nutrients (Harmon and Hua 1991). At early stages of decay, nitrogen concentrations remained relatively constant but phosphorus and potassium decreased (Krankina et al. 1999). As bark decomposed, nutrient concentration in leachate decreased and translocation to woody debris became more dominant. After decay class III, nitrogen and phosphorus concentrations in logs increased and potassium concentrations remained constant (Krankina et al. 1999). Leachate from fresh woody debris can be high in potassium (Krankina et al. 1999, Kuehne et al. 2008), explaining why available potassium was significantly higher on woody debris treatments ($p = 0.100$) (Table 2.9).

Other factors potentially influencing nutrient concentrations include barley on non woody debris treatments and annual fertilizing. At soil sampling, barley had died over winter and was decomposing. In agricultural systems, cover crops are used to immobilize available nitrogen in plant tissue to reduce its loss through leaching or gaseous emissions. To maximize nitrogen retention, cover crops are usually incorporated (Baggs et al. 2000), however not in this study, where the main purpose of barley was to stabilize soil and reduce erosion. Since barley was not incorporated, was not completely decayed, and has a high C:N around 106:1 (Beare et al. 2002), it is likely the barley crop had little influence on the soil available nitrate. Some of the nitrogen in the decomposing barley was likely released and may have contributed to the non woody debris treatment being higher in available nitrogen than the woody debris treatment. Litter decomposition contributes a quicker nutrient release than wood decomposition, which occurs slower and over a longer time period (Harmon et al. 1986). Fertilizer was aerially applied to treatments and contained both nitrogen and phosphorus. Thus, fertilizer would likely influence both treatments similarly and would not explain why woody debris treatments were lower in nitrogen and higher in phosphorus.

4.5 EFFECT OF WOODY DEBRIS ON SOIL PHYSICAL PARAMETERS

Woody debris treatments had a sandy loam texture and non woody debris treatments had a loam, clay loam or sandy clay loam texture. Woody debris treatments had significantly more sand ($p = 0.033$) and less clay ($p = 0.014$) than non woody debris treatments (Table 2.9). Since topsoil was spread over both treatments, treatments likely had similar particle size distribution when plots were constructed. Plots are located in an open area near a road. Due to road traffic, air around the dump is often filled with wind blown particles that likely were trapped by the woody debris and deposited at higher rates on the woody debris plots. This would explain why the cover of woody debris was lower than it was after initial site construction. Some of the woody debris might now be covered by sand.

Several negative effects can occur due to sandy soil textures, including increased nutrient leaching (Carlyle et al. 1998), lower water holding capacity (Sala et al. 1988) and lower microbial biomass (Groffman et al. 1996). According to the inverse texture hypothesis, when precipitation in < 370 mm yr^{-1}, sandy soils are more productive than loam soils due to deeper infiltration, less evaporation and less runoff (Sala et al. 1988). The study site received 192 mm yr^{-1} of precipitation in 2007 (Anderson et al. 2008), thus sandy soils might be beneficial.

4.6 EFFECT OF WOODY DEBRIS ON MICROBIAL PARAMETERS

Treatments without woody debris had significantly higher microbial biomass carbon than treatments with woody debris (Table 2.10; $p < 0.001$). Non woody debris treatments had significantly higher biomass carbon for the rhizospheres of *Calamagrostis canadensis* ($p = 0.003$), *Equisetum arvense* ($p < 0.001$) and *Fragaria virginiana* ($p < 0.001$) (Table 2.10). *Agrostis scabra* was the only species to have a higher microbial biomass in the woody debris treatment; however the difference was not significant. Although initially unexpected, these results can be explained by the abundance of decomposing barley litter (Table 2.2) on the non woody debris sites and the higher proportion of sand on woody debris sites (Table 2.9). Presence of barley straw provided microorganisms with an energy source easier to break down than woody debris. Sandy soils have a lower microbial biomass than loamy soils (Groffman et al. 1996)

Microbial biomass carbon was significantly different among plant species (Table 2.11; $p < 0.001$). Rhizospheres of *Achillea millefolium* and *Calamagrostis canadensis* had the highest microbial biomass carbon and *Agrostis scabra* and

Equisetum arvense had the lowest. This can be explained by the lower proportion of sand on non woody debris sites. *Achillea millefolium* and *Calamagrostis canadensis* have deep spreading roots which required deeper soil rhizosphere samples to be collected. These species had the highest microbial biomass for both non woody and woody debris treatments. If sand was caught by woody debris and deposited on site, it would likely only affect the surface and have less effect at depth where soil texture is probably more similar between treatments. Since deeper samples were collected for these species, the sandy upper layer would have less of an effect on microbial biomass of the entire woody debris sample. Conversely, *Equisetum arvense* has very shallow roots and was likely more affected by the sandy layer, resulting in lowest microbial biomass. It was expected *Agrostis scabra* and *Calamagrostis canadensis* would have similar results since both are grasses with deep fibrous roots. However microbial biomass of *Agrostis scabra* on non woody debris treatments was low.

There was not a significant difference between treatments in glucosamine content (Table 2.10). However, there was a difference among species (Table 2.11; $p < 0.001$). *Calamagrostis canadensis* had significantly higher glucosamine content than other species analyzed. Similar to biomass carbon, *Agrostis scabra* on non woody debris treatments had low glucosamine content for unknown reasons. *Epilobium angustifolium* had the lowest glucosamine content, which was expected since this species has a tap root. Studies similar do not exist, however a tree gap experiment found vegetation growing near sloughed bark fragments or on woody debris had greater mycorrhizal diversity (Vogt et al. 1995).

4.7 INTERRELATIONSHIPS BETWEEN VEGETATION, SOIL, AND MICROORGANISMS

Effect of woody debris on soil chemical, physical and biological properties was measured to determine their influence on vegetation. The woody debris treatment had a coarser texture, lower available nitrogen, higher available phosphorus and lower microbial biomass carbon. Coarser soils can have increased nutrient leaching (Carlyle et al. 1998), lower water holding capacity (Sala et al. 1988) and lower microbial biomass (Groffman et al. 1996). Increased nutrient leaching could be a problem if available nitrogen and phosphorus are limited. Although available phosphorus is higher on the woody debris treatment, available nitrogen is lower.

Nitrogen and phosphorus are important for plant growth and health. Nitrogen is an important part of amino acids, the building blocks of proteins and enzymes which control plant functions. Phosphorus is an integral part of ATP which provides energy for biological processes, DNA, and RNA which drives protein synthesis. Low concentrations of these nutrients can lead to lower functioning in plants and potentially death. Sandier soils and lower microbial biomass carbon could decrease soil aggregation which is associated with soil health since aggregates help control erosion and aid nutrient cycles (Miller and Lodge 1997).

Although coarser soil, lower soil nitrogen, and lower microbial biomass can negatively influence vegetation, microsites appears to be a more dominant factor in seedling survival, increasing species richness and creating a more diverse plant community in early succession. During early stages of succession, high soil surface temperature and evaporation can have dire effects on vegetation trying to establish. Microsites created by woody debris appear to provide seeds and seedlings with extra protection to aid during their most difficult stage of growth.

Reduced beneficial influences of microsites have been demonstrated at later stages of succession (Jones and del Moral 2005). Long term monitoring should continue since higher rates of nitrogen and phosphorus immobilization will likely occur once woody debris is further decayed. Current reclamation practices at Suncor Energy Inc. require reclamation sites to be fertilized for the first five years. Once fertilization stops, nutrient immobilization may have more influence inhibiting plant productivity. As logs complete the decay process, nutrients will be released to the ecosystem. Long term monitoring would help map these transitions and determine trends in progression toward a boreal forest.

5. CONCLUSIONS

Woody debris was beneficial for reclamation, providing microsites for vegetation establishment resulting in greater species richness and planted tree survival. The treatment without woody debris had significantly greater plant canopy cover, but the majority of cover was introduced species, particularly *Sonchus arvensis*, undesirable from a reclamation perspective. Woody debris treatments had significantly less available nitrogen, suggesting nitrogen immobilization and more soil available phosphorus, potentially from woody debris leachate.

6. LITERATURE CITED

Alberta Agriculture. 1988. Recommended methods of soil analysis for Canadian prairie agricultural soils. Alberta Agriculture. 28 pp.

Alberta Department of Energy. 2006. Alberta's oil sands 2005. Government of Alberta. Edmonton, Alberta. 4 pp.

Alberta Environmental Protection. 1994. Draft Alberta tier I criteria for contaminated soil assessment and remediation. Alberta Environmental Protection, Edmonton, Alberta. 196 pp.

American Public Health Association, American Water Works Association, and Water Environment Federation. 2000. Standard methods for the examination of water and wastewater. (20th ed.). American Public Health Association. Washington DC.

Anderson, P., W. Tedder, L. Paquim, M. Mamer and L. Cox. 2008. Conservation and reclamation report for the year 2007. Suncor Energy Inc. Oil Sands. Fort McMurray, Alberta. 214 pp.

Appuhn, A. and R.G. Joergensen. 2006. Microbial colonisation of roots as a function of plant species. Soil Biology and Biochemistry 38:1040-1051.

Appuhn, A., R.G. Joergensen, M. Raubuch, E. Scheller and B. Wilke. 2004. The automated determination of glucosamine, galactosamine, muramic acid, and mannosamine in soil and root hydrolysates by HPLC. Journal of Plant Nutrition and Soil Science 167:17-21.

Auerswald, K. and S. Weigand. 1996. Ecological impact of dead-wood hedges; release of dissolved phosphorus and organic matter into runoff. Ecological Engineering 7:183-189.

Baggs, E.M., C.A. Watson and R.M. Rees. 2000. The fate of nitrogen from incorporating cover crop and green manure residues. Nutrient Cycling in Agroecosystems 56(2):153-163.

Beach, E.W. and C.B. Halpern. 2001. Controls on conifer regeneration in managed riparian forests: effect of seed source, substrate, and vegetation. Canadian Journal of Forest Research 31:471-482.

Beare, M.H., P.E. Wilson, P.M. Fraser and R.C. Butler. 2002. Management effects on barley straw decomposition, nitrogen release, and crop production. Soil Science Society of America Journal 66(3):848-856.

Bremner, J.M. 1996. Nitrogen-total (Dumas methods). In: J.M. Bartels (ed.). Methods of Soil Analysis: Part 3 Chemical Methods. (3rd ed.). American Society of Agronomy, Inc. and Soil Science Society of America. Madison, Wisconsin, USA. Book series no. 5. 1088 pp.

Brennan, K.E.C., O.G. Nichols and J.D. Majer. 2005. Innovative techniques for promoting faunal return to rehabilitated sites following mining. Australian Centre for Minerals Extension and Research (ACMER), Brisbane and Minerals and Energy Research Institute of Western Australia (MERIWA Report 248). Perth, Australia. 123 pp.

Brunner, A. and J.P. Kimmins. 2003. Nitrogen fixation in coarse woody debris of *Thuja plicata* and *Tsuga heterophylla* forests on northern Vancouver Island. Canadian Journal of Forest Research 33:1670-1682.

Carlyle, J.C., M.W. Bligh and E.K. Sadanandan Nambiar. 1998. Woody residue management to reduce nitrogen and phosphorus leaching from sand soil after clear-felling *Pinus radiate* plantations. Canadian Journal of Forest Research 28:1222-1232.

Carter, M.R. and E.G. Gregorich. 2008. Soil sampling and methods of analysis (2nd ed.). Canadian Society of Soil Science. Taylor & Francis Group. Florida, USA.

Christy, E.J. and R.N. Mack. 1984. Variation in demography of juvenile *Tsuga heterophylla* across the substratum mosaic. Journal of Ecology 72(1):75-91.

Debeljak, M. 2006. Coarse woody debris in virgin and managed forest. Ecological Indicators 6:733-742.

DePuit, E.J. 1984. Potential topsoiling strategies for enhancement of vegetation diversity on mined lands. Minerals and the Environment 6:115-120.

Environment Canada. 2003. Canadian climate normals 1971 - 2000. http://www.climate.weatheroffice.ec.gc.ca/climate_normals/results_e.html. accessed April 2009. Meteorological Service of Canada, Environment Canada, Government of Canada.

Fung, M.Y.P. and T.M. Macyk. 2000. Reclamation of oil sands mining areas. In: Reclamation of drastically disturbed lands. Agronomy Monograph 41. Pp. 755-774.

Government of Alberta. 2009. Environmental management of Alberta's oil sands: resourceful. Responsible. Government of Alberta, Canada. Edmonton, Alberta. 24 pp.

Graham, S.A. 1925. The felled tree trunk as an ecological unit. Ecology 6(4):397-411.

Grey, A.N. and T.A. Spies. 1997. Microsite controls on tree seedling establishment in conifer forest canopy gaps. Ecology 78(8): 2458-2473.

Groffman, P.M., P. Eagan, W.M. Sullivan and J.L. Lemunyon. 1996. Grass species and soil type effects on microbial biomass and activity. Plant and Soil 183(1):61-67.

Grubb, P.J. 1977. The maintenance of species-richness in plant communities: the importance of the regeneration niche. Biological Reviews 52(1):107-145.

Hafner, S.D., P.M. Groffman and M.J. Mitchell. 2005. Leaching of dissolved organic carbon, dissolved organic nitrogen, and other solutes from coarse woody debris and litter in a mixed forest in New York state. Biogeochemistry 74:257-282.

Harmon, M.E., J.F. Franklin, F.J. Swanson, P. Sollins, S.V. Gregory, J.D. Lattin, N.H. Anderson, S.P. Cline, N.G. Aumen, J.R.Sedell, G.W. LienKaemper, K.

Cromack Jr. and K.W. Cummins. 1986. Ecology of coarse woody debris in temperate ecosystems. Advances in Ecological Research 15:133-302.

Harmon, M.E. and C. Hua. 1991. Coarse woody debris dynamics in two old-growth ecosystems: comparing a deciduous forest in China to a conifer forest in Oregon. Bioscience 41(9):604-610.

Harper, J.L., J.N. Clatworthy, I.H. McNaughton and G.R. Sagar. 1961. The evolution and ecology of closely related species living in the same area. Evolution 15(2):209-227.

Hicks, W.T., M.E. Harmon and D.D. Myrold. 2003. Substrate controls on nitrogen fixation and respiration in woody debris from the Pacific Northwest, USA. Forest Ecology and Management 176:25-35.

Hofgaard, A. 1993. 50 years of change in a Swedish boreal old-growth *Picea abies* forest. Journal of Vegetation Science 4(6):773-782.

Jones, C.C., and R. del Moral. 2005. Effects of microsite conditions on seedling establishment on the foreland of Coleman Glacier, Washington. Journal of Vegetation Science 16:293-300.

Jumpponen, A., H. Vare, K.G. Mattson, R. Ohtonen and J.M. Trappe. 1999. Characterization of ‘safe sites’ for pioneers in primary succession on recently deglaciated terrain. Journal of Ecology 87(1):98-105.

Kalra, Y.P. and D.G. Maynard. 1991. Methods manual for forest soil and plant analysis. Forestry Canada northwest region northern forestry center. Rep. NOR-X-319. Forestry Canada, Northwest Region, Northern Forestry Center, Edmonton, Alberta. Pp. 46-53.

Kayahara, G.J., K. Klinka and L.M. Lavkulich. 1996. Effects of decaying wood on eluviation, podzolization, acidification, and nutrition in soils with different moisture regimes. Environmental Monitoring and Assessment 39:485-492.

Krankina, O.N., M.E. Harmon and A.V. Griazkin. 1999. Nutrient stores and dynamic of woody detritus in a boreal forest: modeling potential implications at the stand level. Canadian Journal of Forest Research 29:20-32.

Kuehne, C., C. Donath, S.I. Muller-Using and N. Bartsch. 2008. Nutrient fluxes via leaching from coarse woody debris in a Fagus sylvatica forest in the Solling Mountains, Germany. Canadian Journal of Forest Research 38:2405-2413.

Laiho, R. and C.E. Prescott. 1999. The contribution of coarse woody debris to carbon, nitrogen, and phosphorus cycles in three Rocky Mountain coniferous forests. Canadian Journal of Forest Research 29:1592-1603.

Loeppert, R.H. and D.L. Suarez. 1996. Gravimetric method for loss of carbon dioxide. In: J.M. Bartels (ed.). Methods of Soil Analysis: Part 3 Chemical Methods. (3rd ed.). American Society of Agronomy, Inc. and Soil Science Society of America. Madison, WI, USA. Book series no. 5. Pp. 455-456.

MacKenzie, D.D. and M.A. Naeth. 2007. Assisted natural recovery using a forest soil propagule bank in the Athabasca oil sands. Seeds: Biology, Development and Ecology. Pp. 374-382.

Miller, R.M. and D.J. Lodge. 1997. Five fungal responses to disturbance:

agriculture and forestry. In: Esser K., P.A. Lemke, D.T. Wicklow. The Mycota. Berlin: Springer-Verlag. Pp. 65-48.

Moss, E.H. 1994. Flora of Alberta: a manual of flowering plants, conifers, ferns and fern allies found growing without cultivation in the province of Alberta, Canada. University of Toronto Press. Toronto, Ontario. 687 pp.

Natural Regions Committee. 2006. Natural regions and subregions of Alberta. Compiled by D.J. Downing and W.W. Pettapiece. Government of Alberta. Edmonton, Alberta. Pub. No. T/852.

Nelson, D.W. and L.E. Sommers. 1996. Total carbon, organic carbon, and organic matter. In: J.M. Bartels (ed.). Methods of Soil Analysis: Part 3 Chemical Methods. (3rd ed.). American Society of Agronomy, Inc. and Soil Science Society of America. Madison, Wisconsin, USA. Book series no. 5. Pp. 961-1010.

Nilsson, K. and J. Bjurman. 1998. Chitin as an indicator of the biomass of two wood-decay fungi in relation to temperature, incubation time, and media composition. Canadian Journal of Microbiology 44:575-581.

Oil Sands Revegetation Reclamation Committee. 1998. Guidelines to reclamation to forest vegetation in the Athabasca Oil Sands Region. Fort McMurray, Alberta. 212 pp.

Pyle, C. and M.M. Brown. 1999. Heterogeneity of wood decay classes with hardwood logs. Forest Ecology and Management 144:253-259.

Qian, P., J.J. Schoenaru and R.E. Karamanos. 1994. Simultaneous extraction of available phosphorus and potassium with a new soil test: A modification of Kelowna extract. Communications in Soil Science and Plant Analysis 25(5&6):627-635.

Sala, O.E., W.J. Parton, L.A. Joyce and W.K. Lauenroth. 1988. Primary production of the central grassland region of the United States. Ecology 69(1):40-45.

Siitonen, J. 2001. Forest management, coarse woody debris and saproxylic organisms: Fennoscandian boreal forests as an example. Ecological Bulletins 49:11-41.

Singh, K. 2007. Approval: province of Alberta, environmental protection and enhancement act. R.S.A. 2000, c.E-12, as amended. Alberta Environment. Suncor Energy, Inc. Fort McMurray, Alberta. 105 pp.

Sinsabaugh, R.L., R.K. Antibus, A.E. Linkins, C.A. McClaugherty, L. Rayburn, D. Repert and T. Weiland. 1993. Wood decomposition: nitrogen and phosphorus dynamics in relation to extracellular enzyme activity. Ecology 74(5):1586-1593.

Stevens, V. 1997. The ecological role of coarse woody debris: an overview of the ecological importance of CWD in BC forests. Research Branch, British Columbia Ministry of Forests, Victoria, British Columbia. Working Paper 30/1997.

Vance, E.D., P.C. Brookes and D.S. Jenkinson. 1987. An extraction method for measuring soil microbial biomass C. Soil Biology and Biochemistry 19(6):703-

707.

Vogt, K.A., D.J. Vogt, H. Asbjornsen and R.A. Dahlgren. 1995. Roots, nutrients and their relationship to spatial patterns. Plant and Soil 168-169(1):113-123.

Wells J.M. and L. Boddy. 1990. Woody decay, and phosphorus and fungal biomass allocation, in mycelial cord systems. New Phytologist 116:285-295.

Whisenant, S. 2005. 50 first steps in erosion control. Forest Restoration in Landscapes. Springer, New York, New York. Pp. 350-351.

Winter Sydnor, M.E. and E.F. Redente. 2002. Ecosystem restoration: reclamation of high-elevation, acidic mine waste with organic amendments and topsoil. Journal of Environmental Quality 31:1528-1537.

Zar, J.H. 1999. Biostatistical analysis. (4th ed.). Prentice Hall. Upper Saddle River, New Jersey. 660 pp.

Zimmerman J.K., W.M. Pulliam, D.J. Lodge, V. Quinones-Orfila, N. Fetcher, S. Guzmán-Grajales, J.A. Parrotta, C.E. Asbury, L.R. Walker and R.B. Waide. 1995. Nitrogen immobilization by decomposing woody debris and the recovery of tropical wet forest from hurricane damage. Oikos 72:314-322.

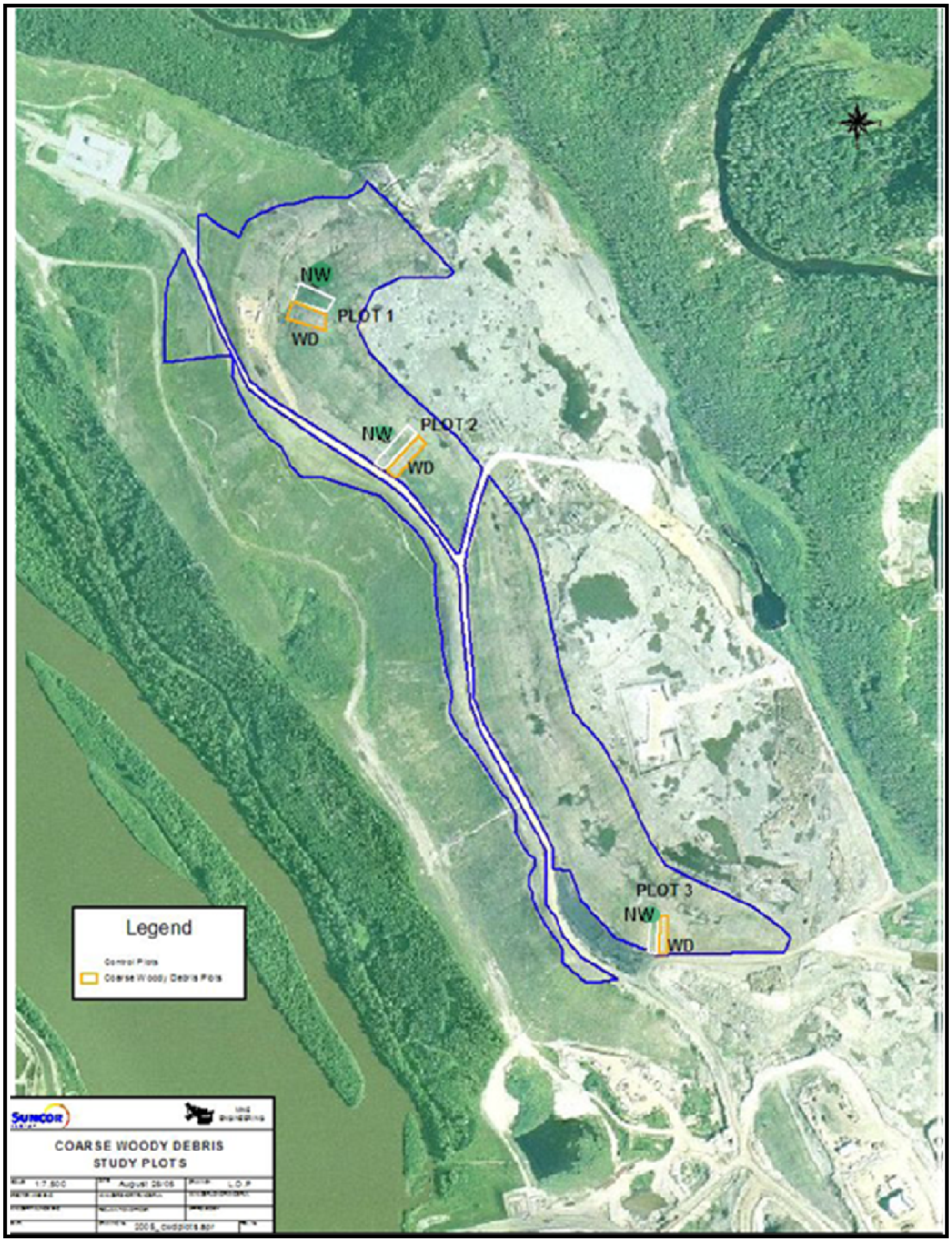

Figure 2.1 Locations of woody debris (WD) and non woody debris (NW) treatment plots along the steep bank north dump at Suncor Energy Inc.

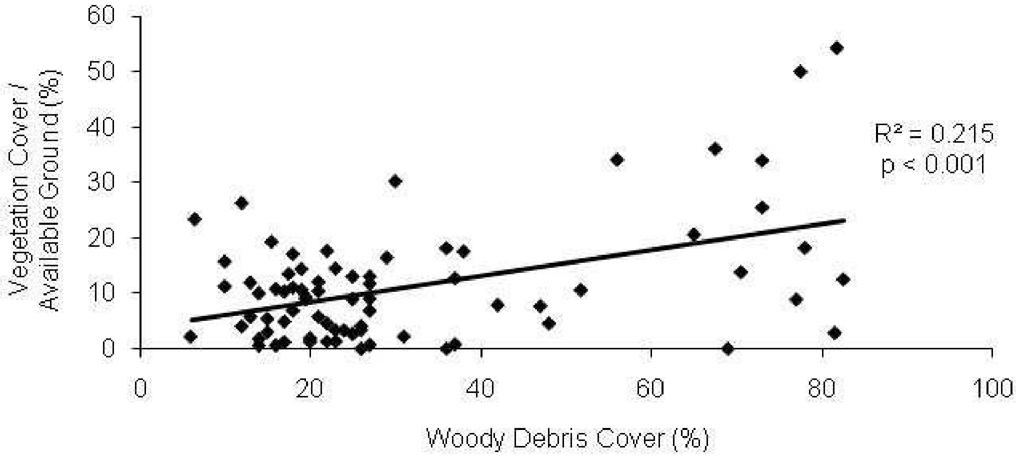

Figure 2.2 Regression analysis for relationship between vegetation cover per available ground and woody debris cover (n = 76).

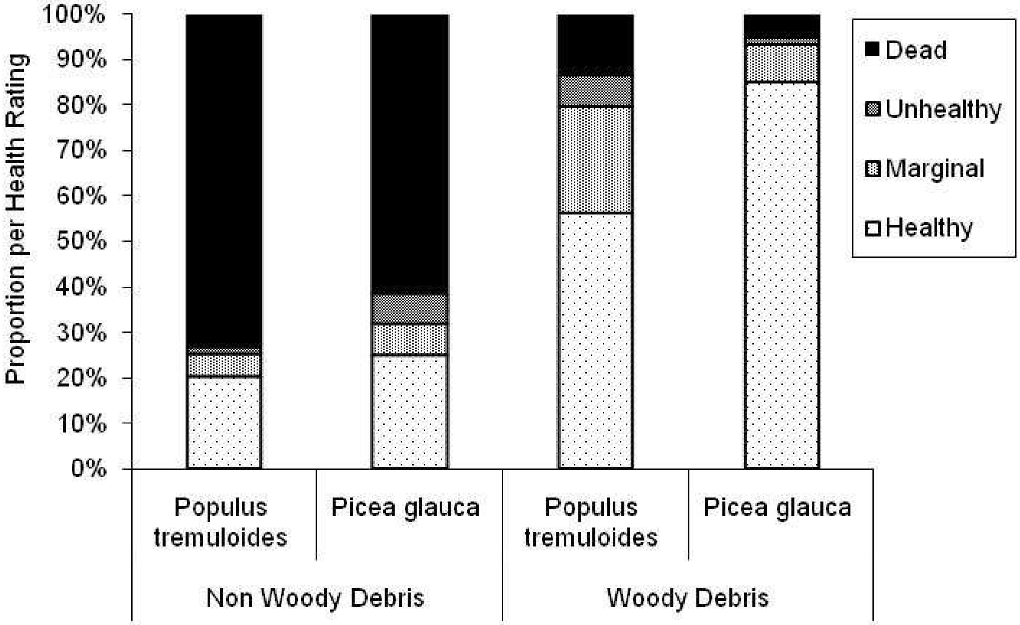

Figure 2.3 Mean proportion of health ratings for planting saplings after three years of growth (n = 3).

Table 2.1 Experimental site description of the four year old research site.

	Plot Pair 1	Plot Pair 2	Plot Pair 3
Length x Width	80 x 30 m	80 x 20 m	80 x 15 m
Slope	34%	23%	32%
Aspect	290°	220°	180°
Mean Woody Debris Cover	WD: 28.9 (19.6) NW: 0.5 (0.6)	WD: 43.5 (27.8) NW: 0.8 (0.8)	WD: 24.7 (12.9) NW: 1.4 (1.3)
Number of Planted Saplings	WD: 19 *Populus*, 20 *Picea* NW: 20 *Populus*, 18 *Picea*	WD: 20 *Populus*, 20 *Picea* NW: 19 *Populus*, 20 *Picea*	WD: 20 *Populus*, 20 *Picea* NW: 20 *Populus*, 20 *Picea*

Mean woody debris covers are means with standard deviation in brackets.

Table 2.2 Mean species richness and percent canopy cover (per 1 m^2) in woody debris and non woody debris treatments four years after reclamation (n = 3).

		Woody Debris	Non Woody Debris
Species Richness		25 (3)	20 (2)
Vegetation	%	6.5 (0.7)^b	13.1 (0.9)^a
Bare Ground	%	21.6 (4.2)	19.7 (7.6)
Litter	%	37.9 (5.3)^b	64.1 (7.8)^a
Woody Debris	%	32.4 (5.7)^a	0.9 (0.3)^b
Rock	%	1.4 (0.3)	1.4 (0.3)
Moss	%	0.3 (0.2)	2.1 (1.2)
Available Ground	%	66.2 (5.7)^b	97.7 (0.5)^a
Vegetation / Available Ground	%	10.2 (2.1)	13.4 (0.9)

Numbers are means followed by standard errors in brackets.
Different letters denote significance between treatments at $p < 0.100$.

Table 2.3 Mean percent canopy cover (per 1 m^2) of plant groups in woody debris and non woody debris treatments four years after reclamation (n = 3).

Groups	Woody Debris	Non Woody Debris
Total	6.8 (0.7)^b	13.2 (1.0)^a
Grass	0.9 (0.5)	1.6 (0.8)
Sedge	< 0.1	< 0.1
Forb	4.8 (0.8)^b	11.0 (1.1)^a
Pteridophyte	0.6 (0.6)	0.5 (0.2)
Woody	0.5 (0.3)	0.1 (0.1)
Native	4.9 (0.3)	5.4 (0.7)
Introduced	1.5 (0.9)^b	7.8 (1.6)^a
Perennial	6.4 (0.5)^b	11.8 (0.5)^a
Annual/Biennial	0.4 (0.3)	1.5 (1.0)

Numbers are means followed by standard errors in brackets.
Different letters denote significance between treatments at $p < 0.100$.

Table 2.4 Mean percent canopy cover of most common species (per 1 m^2) in woody debris and non woody debris treatments four years after reclamation (n = 3).

Species	Morphology	Woody Debris	Non Woody Debris
Native Species			
Achillea millefolium	Forb	< 0.1	0.2 (0.1)
Aster ciliolatus	Forb	0.1 (0.0)	0.1 (0.0)
Calamagrostis canadensis	Grass	0.1 (0.0)	0.8 (0.8)
Epilobium angustifolium	Forb	2.8 (0.1)	2.0 (1.3)
Equisetum arvense	Pteridophytee	0.60 (0.6)	0.5 (0.2)
Erigeron canadensis	Forb	0.4 (0.2)	1.2 (0.8)
Fragaria virginiana	Forb	< 0.1	0.2 (0.1)
Hieracium umbellatum	Forb	0.1 (0.0)	0.1 (0.0)
Hordeum jubatum	Grass	0.7 (0.6)	0.8 (0.7)
Salix spp.	Shrub	0.4 (02.)	< 0.01
Urtica dioica	Forb	< 0.01	0.2 (0.2)
Introduced Species			
Sonchus arvensis	Forb	1.1 (0.7)^b	6.5 (1.3)^a

Numbers are means followed by standard errors in brackets.
Different letters denote significance between treatments at $p < 0.100$.

Table 2.5 Presence (+) absence (-) of species on a four year old reclamation site on woody debris (WD) or non woody debris (NW) treatments.

Species	Woody Debris	Non Woody Debris
Grasses		
Agropyron trachycaulum (Link) Malte	+	-
Agrostis scabra Willd.	+	-
Calamagrostis canadensis (Michx.) Beauv.	+	+
Deschampsia cespitosa (L.) Beauv.	+	-
Hordeum jubatum L.	+	+
Poa palustris L.	+	+
Sedges		
Carex spp. L.	+	+
Forbs		
Achillea millefolium L.	+	+
Achillea sibirica Ledeb.	-	+
Aster ciliolatus Lindl.	+	+
Astragalus americanus (Hook.) M.E. Jones	-	+
Astragalus canadensis L.	-	+
Chenopodium album L.	-	+
Dracocephalum parviflorum Nutt.	+	-
Epilobium angustifolium L.	+	+
Epilobium glandulosum (Lehm.) Hoch & Raven	+	+
Erigeron canadensis L.	+	+
Fragaria virginiana Duchesne	+	+
Galium boreale L.	+	+
Gentianella amarella (L.) Börner	-	+
Geranium bicknellii Britt.	+	-
Hieracium umbellatum L.	+	+
Lathyrus ochroleucus Hook.	+	-
Lathyrus venosus Muhl.	+	-
Maianthemum canadense Desf.	+	-
Medicago sativa L.	+	+
Melilotus alba Desr.	+	-
Mertensia paniculata (Ait.) G. Don	+	-
Mitella nuda L.	+	-
Petasites palmatus (Ait.) A. Gray	+	-
Petasites sagittatus (Pursh) A. Gray	+	+
Plantago major L.	-	+
Potentilla norvegica L.	+	+
Rubus pubescens Raf.	-	+
Rumex occidentalis S. Wats.	-	+
Sonchus arvensis L.	+	+
Stellaria longifolia Muhl.	+	+
Taraxacum officinale Weber	+	+
Thalictrum venulosum Trel.	+	-
Trientalis borealis Raf.	+	-

Table 2.5 Presence (+) absence (-) of species on the four year old reclamation site on either woody debris (WD) or non woody debris (NW) treatments (continued).

Species	Woody Debris	Non Woody Debris
Urtica dioica L.	+	+
Vicia americana Muhl.	+	+
Pteridophyte		
Equisetum arvense L.	+	+
Woody		
Amelanchier alnifolia Nutt.	+	-
Cornus sericea L.	+	+
Ribes hudsonianum Richards.	+	+
Ribes oxyacanthoides L.	+	+
Rosa acicularis Lindl.	+	+
Rubus idaeus L.	+	+
Salix spp. L.	+	+
Shepherdia canadensis (L.) Nutt.	+	+
Spiraea alba Du Roi	-	+
Symphoricarpos occidentalis Hook.	+	-
Total	42	35

Table 2.6 Mean proportion of planted saplings per presence classification after three years of growth (Species n = 3, Total n = 6).

Species	Present		Missing	
	Woody Debris	Non Woody Debris	Woody Debris	Non Woody Debris
Picea glauca	95 (3)^a	39 (24)^b	5 (3)^b	61 (24)^a
Populus tremuloides	88 (7)^a	27 (14)^b	12 (7)^b	73 (14)^a
Total	92 (4)^a	33 (13)^b	8 (4)^b	67 (13)^a

Numbers are means followed by standard errors in brackets.
Different letters denote significance between treatments at $p < 0.100$.

Table 2.7 Mean proportion of planted saplings per health classification after three years of growth (Species n = 3, Total n = 6).

Species	Healthy		Marginal		Unhealthy		Dead	
	Woody Debris	Non Woody Debris	Woody Debris	Non Woody Debris	Woody Debris	Non Woody Debris	Woody Debris	Non Woody Debris
Picea glauca	85 (5)^{a}	25 (14)^{b}	8 (8)	7 (4)	2 (2)	7 (7)	5 (3)^{b}	61 (24)^{a}
Populus tremuloides	56 (17)^{a}	20 (10)^{b}	23 (10)	5 (3)	7 (2)	2 (2)	13 (9)^{b}	73 (14)^{a}
Total	71 (10)^{a}	23 (8)^{b}	16 (7)	6 (2)	4 (2)	4 (3)	9 (5)^{b}	67 (13)^{a}

Numbers are means followed by standard errors in brackets.
Different letters denote significance between treatments at $p < 0.100$.

Table 2.8 Mean height (cm) of saplings three years after planting in woody debris and non woody debris treatments (n = 3).

Species	Woody Debris	Non Woody Debris
Picea glauca	39.3 (0.9)^{a}	24.5 (4.8)^{b}
Populus tremuloides	86.8 (3.8)	96.6 (18.2)

Numbers are means followed by standard errors in brackets.
Different letters denote significance between treatments at $p < 0.100$.

Table 2.9 Mean soil chemical and physical properties of a four year old site in woody debris and non woody debris treatments (n = 3).

	Units	Woody Debris	Non Woody Debris
Total Carbon	%	4.8 (0.3)^{b}	10.3 (1.1)^{a}
Total Organic Carbon	%	4.7 (0.3)^{b}	10.1 (1.1)^{a}
Total Nitrogen	%	0.2 (0.0)^{b}	0.4 (0.1)^{a}
C:N		25.5 (2.1)	25.4 (1.6)
Available Nitrate	mg/kg	1.5 (0.1)^{b}	2.9 (0.3)^{a}
Available Phosphorus	mg/kg	13.7 (3.8)^{a}	4.7 (1.2)^{b}
Available Potassium	mg/kg	100.7 (0.7)^{a}	94.7 (2.7)^{b}
Available Sulphate	mg/kg	52.7 (19.8)	52.0 (14.2)
Sodium Adsorption Ratio		0.7 (0.3)	0.7 (0.3)
Electrical Conductivity	dS/m	0.8 (0.1)	0.6 (0.1)
pH		7.0 (0.1)	7.1 (0.0)
Sand	%	63.3 (4.9)^{a}	46.7 (1.8)^{b}
Silt	%	25.0 (3.2)	26.3 (4.1)
Clay	%	11.7 (2.7)^{b}	27.0 (2.5)^{a}

Numbers are means followed by standard errors in brackets.
Different letters denote significance between treatments at $p < 0.100$.

Table 2.10 Mean microbial biomass carbon for the rhizosphere and mean glucosamine content for the roots of six species per treatment with and without woody debris from a four year old reclamation site.

	Microbial Biomass Carbon (ppm)		Glucosamine (mg) / Oven Dried Root (g)	
	Woody Debris	Non Woody Debris	Woody Debris	Non Woody Debris
Total	48.4 (6.1)^{b}	83.7 (12.5)^{a}	16. (2.4)	15. (2.4)
Achillea millefolium	83.4 (6.3)	98.3 (6.4)	14. (1.8)	13. (0.36)
Agrostis scabra	41.6 (1.5)	29.1 (4.3)	18. (8.6)	6.4 (0.76)
Calamagrostis Canadensis	57.3 (3.2)^{b}	93.7 (7.0)^{a}	31. (3.9)	33. (6.3)
Epilobium angustifolium	-	-	6.0 (0.27)	7.4 (0.73)
Equisetum arvense	16.2 (4.5)^{b}	71.3 (10.0)^{a}	10. (0.57)	13. (1.7)
Fragaria virginiana	43.4 (4.3)^{b}	88.7 (17.2)^{a}	15. (3.7)	17. (3.1)

Numbers are means followed by standard errors in brackets.
No soil rhizosphere was collected for *Epilobium angustifolium*.
(Microbial Biomass C Total n = 15, Glucosamine Total n = 18, Species n = 3)

Table 2.11 Mean microbial biomass carbon for the rhizosphere and mean glucosamine content for the roots per species from a four year old reclamation site (n = 6).

	Achillea millefolium	*Agrostis scabra*	*Calamagrostis canadensis*	*Epilobium angustifolium*	*Equisetum arvense*	*Fragaria virginiana*
Microbial Biomass Carbon (ppm)	90.9 (5.2)^{a}	35.3 (3.5)^{c}	75.5 (8.8)^{ab}	-	43.7 (13.3)^{c}	66.0 (12.9)^{b}
Glucosamine (mg) / Oven Dried Root (g)	13. (0.86)^{b}	12. (4.6)^{b}	32. (3.3)^{a}	6.7 (0.47)^{b}	12.(1.0)^{b}	16. (2.2)^{b}

Numbers are means followed by standard errors in brackets.
No soil rhizosphere was collected for *Epilobium angustifolium*.
Different letters denote significance at $p < 0.100$.

CHAPTER III. EFFECTS OF WOODY DEBRIS ON VEGETATION ESTABLISHMENT AND SOIL PROPERTIES TWO YEARS AFTER RECLAMATION IN THE ATHABASCA OIL SANDS REGION, ALBERTA, CANADA.

1. INTRODUCTION

Boreal forests in northern Alberta, Canada are impacted by severe anthropogenic disturbances from oil sands mining. Oil sands are a naturally occurring resource consisting of bitumen, sand and water (Government of Alberta 2009). Three deposits underlie 142,200 km^2 of land in Alberta, the largest in the Athabasca Oil Sands Region. Here, deep pit surface mining is the preferred oil sands removal method for 4,800 km^2 of land. Over 600 km^2 have been disturbed (Government of Alberta 2009), making oil sands development one of the largest anthropogenic disturbances in the world. In surface mined areas, oil sands are located approximately 40 to 60 m below ground (National Energy Board 2000), requiring removal of several ecological layers and complete ecosystem redevelopment for reclamation. Companies are required to reclaim to equivalent capability to predisturbance conditions (Oil Sands Revegetation Reclamation Committee 1998).

Reclamation often relies on applying cover soils to restore vegetation diversity and soil function (DePuit 1984, Winter Sydnor and Redente 2002, MacKenzie and Naeth 2007). Cover soils increased organic matter, available nutrients, microorganisms, water holding capacity (Winter Sydnor and Redente 2002) and native seeds and propagules (DePuit 1984, Mackenzie and Naeth 2007). Cover soils of peat mineral mix and upland surface soil are common for oil sands reclamation (Singh 2007). Peat mineral mix is comprised of 1 m of organic peat with 0.4 m of underlying mineral soil (Oil Sands Revegetation Reclamation Committee 1998, Singh 2007) (hereafter referred to as peat). Upland surface soil is a mix of LFH and Ae horizons from Luvisolic soils, including fine roots and tree stumps (hereafter referred to as LFH). LFH is a forest floor layer comprised of identifiable litter (L), fragmented and fermenting litter (F) and humus (H).

LFH is known to have a large propagule bank (Mackenzie and Naeth 2007). MacKenzie (2006) found greater soil surface microtopography and vegetation cover on LFH cover soils than peat cover soils. Other researchers noted the importance of microtopography or microsites to early succession pathways for protecting seeds and seedlings from environmental stressors and providing a favourable growing habitat (Harper et al. 1965, Oswald and Neuenschwander 1993, Jumpponen et al. 1999, Jones and del Moral 2005).

Adding woody debris to a degraded landscape may aid site development by creating microsites. Large quantities of woody debris are collected as land is cleared for mining, Woody debris is defined as all dead woody material in a forest ecosystem including dead wood on the soil surface such as logs, fallen limbs, twigs and woody fruit; dead roots and buried wood below ground; and standing snags and stumps (Pyle and Brown 1999). As forests are cleared, merchantable timber is sold and the remainder is burnt in piles or disposed of in large pits.

Few studies have analyzed the benefits of using woody debris in reclamation, except to note its ability to reduce soil erosion (Stevens 1997, Whisenant 2005). Studies in forest ecosystems found a variety of ecological functions supported by woody debris. Dead logs provided habitat and shelter for numerous organisms (Graham 1925, Harmon et al. 1986, Siitonen 2001, Brennan et al. 2005, Debeljak 2006), increased microbial presence (Harmon et al. 1986, Pyle and Brown 1999, Hicks et al. 2003), aided nutrient cycling (Harmon et al. 1986, Pyle and Brown 1999, Hicks et al. 2003, Hafner et al. 2005) and increased plant growth (Christy and Mack 1984, Hofgaard 1993) and productivity (Siitonen 2001, Debeljak 2006). Woody debris can stabilize nutrients after major disturbances (Harmon and Hua 1991) by preventing excessive leaching (Harmon et al. 1986, Carlyle et al. 1998) and immobilizing nutrients in woody and microbial biomass (Harmon et al. 1986, Wells and Boddy 1990, Sinsabaugh et al. 1993, Laiho and Prescott 1999). With time, woody material decays and nutrients are released into the soil (Harmon et al. 1986, Zimmerman et al. 1995). Since woody debris has ecological value in forest ecosystems it may have a similar value in reclamation.

2. OBJECTIVES

This study aimed to determine if applying *Populus tremuloides* Michx. (trembling aspen) mixed wood and *Picea mariana* Mill. BSP. (black spruce) woody debris over peat or LFH cover soil would enhance reclamation after oil sands mining. Specific objectives were as follows.

- Determine effects of woody debris presence, species and size on soil chemical properties, such as available nutrients, carbon nitrogen ratio, sodium absorption ratio, electrical conductivity and pH.
- Determine effects of woody debris presence, species and size on surface soil temperature range and volumetric water content.
- Determine effects of woody debris presence, species and size on microbial biomass carbon and woody debris presence and species on mycorrhizal biomass.
- Determine effects of woody debris on plant canopy cover, biovolume, composition and richness.
- Determine effects of woody debris on woody species abundance.
- Determine if woody debris creates microsites for plant growth by determining if more vegetation grows in close proximity to woody debris.
- Determine if cover soil type influences the first five parameters listed above.

3. METHODS

3.1 RESEARCH SITE DESCRIPTION

Research was conducted at Suncor Energy Inc., 24 km north of Fort McMurray, Canada. The site was located in the central mixed wood natural subregion of the boreal forest natural region (Natural Regions Committee 2006). This area generally has long cold winters and short warm summers. Fort McMurray has an average annual temperature of 0.7 ℃. Mean maximum temperature typically occurs in July at 23.2 ℃ and minimum temperature occurs in January at -24 ℃. Average annual precipitation is 455.5 mm, with 342.2 mm falling as rain and 155.8 cm as snow (Environment Canada 2003).

The central mixed wood natural subregion consists of large areas of upland forest, wetlands and rolling plains. Upland forests are most commonly composed of *Populus tremuloides* and *Picea glauca* (white spruce) mixed wood stands, however *Populus balsamifera* L. (balsam poplar) and *Pinus banksiana* Lamb.

(jack pine) can occur. Soils of upland stands are mainly Gray Luvisols with some Dystric and Eutric Brunisols. Wetlands are dominated by *Picea mariana* bogs and fens, with *Salix* sp. (willow), *Ledum glandulosum* Nutt. (Labrador tea) and sedge species. Bogs and fens have organic soils, predominantly Mesisols, and gleying occurs in some depressions (Natural Regions Committee 2006).

3.2 EXPERIMENTAL DESIGN, TREATMENTS AND PLOT ESTABLISHMENT

Research plots were located on the southeast dump at Suncor Energy Inc. and covered 70 x 300 m² of land on a slight east facing slope. The site was cleared in 1999 and used as a dump for saline sodic overburden waste. Material was last placed in 2004. Between November 2007 and February 2008, six treatments were established to study LFH and peat covered substrates with no woody debris, or with woody debris from *Picea mariana* or *Populus tremuloides* mixed wood forests. Two rows of plots were arranged horizontally along the slope of the study site in a complete randomized block design. Each block was 10 m wide and 30 m long (Figure 3.1) and each row contained three replicates of each treatment for a total of 36 treatment plots. Each plot was separated by a 5 m buffer and the two rows were separated by a 10 m buffer.

Half the cover soil treatment plots received LFH and half received peat. LFH was salvaged to a depth of 20 cm and applied at a depth of 20 cm, over 30 cm of B and C mix horizon subsoil and 100 cm of clean overburden. Peat was applied at a depth of 30 cm over 100 cm of clean overburden. Covers were applied between November 22 and December 2, 2007 and spread with a Caterpillar D6 bulldozer. For each cover type, six plots were covered with *Picea mariana* woody debris, six were covered with *Populus tremuloides* mixed wood woody debris, and six were controls with no added woody debris (Figure 3.1).

Populus tremuloides mixed wood debris contained approximately 70% *Populus tremuloides*, 30% *Picea glauca* and trace amounts of *Betula papyrifera* Marsh. (paper birch). Woody debris was fresh salvaged in February 2008 and transported with a Caterpillar 740 articulated dump truck. It was applied February 12 to 14 with a Caterpillar 320C backhoe with grapple device. All debris was arranged to provide maximum contact with the soil surface. Plots were aerially fertilized in June 2008 with a 23.5 nitrogen: 25 phosphorus: 8 potassium fertilizer at 300 kg ha^{-1} and in August 2009 with a 31.5:16:5 fertilizer at 250 kg ha^{-1}.

Woody debris cover per plot averaged 10 to 40% (Tables 3.1 and 3.2). *Picea mariana* treatments had higher cover due to the greater abundance of small and fine sized woody debris. Prior to data collection, woody debris was divided into four size classes: fine woody debris with a diameter of $\leq$ 2 cm; small woody debris with a diameter between 2 and 5 cm; medium woody debris with a diameter between 5 and 15 cm; and large woody debris with a diameter > 15 cm.

3.3 SOIL CHEMICAL AND PHYSICAL SAMPLING AND ANALYSES

Soil samples were collected from all treatments in May 2008, August 2008, June 2009 and August 2009 with a 5 cm diameter dutch auger at 0 to 10 cm depth. In each woody debris plot, three samples were collected under large woody debris and composited and three samples were collected under small woody debris and composited. In control plots, three samples were collected away from woody debris and composited. In May 2008 samples were collected next to pieces of woody debris; for other sampling times samples were collected directly under logs. In May 2008, samples were also collected from 35 to 45 cm in overburden under peat and BC horizon under LFH for site characterization (Appendices B.2 and B.3). In August 2009, samples were also collected from 0 to 5 cm depth to determine effects of woody debris at shallow depths (Appendix B.4). Results did not differ significantly from 0 to 10 cm depths and were thus not discussed in this chapter. Samples were sealed in plastic bags and refrigerated until analyzed within three weeks of collection.

Samples were analyzed at Exova commercial laboratory in Edmonton, Alberta. Available phosphorus and potassium were determined with a modified Kelowna extraction method (Ashworth and Mrazek 1995). Available nitrate (NO_3^-) was determined by this method for May 2008 and August 2009 samples; for August 2008 and June 2009 samples, available nitrate and ammonium (NH_4^+) were determined by extraction with 2.0 M KCl (Carter and Gregorich 2008). Available sulphate (SO_4) was determined by extraction with 0.1 M $CaCl_2$ (McKeague 1978). Total carbon and total nitrogen were determined by dry combustion (Nelson and

Sommers 1996, Bremner 1996). Inorganic carbon was determined by CO_2 release (Loeppert and Suarez 1996). Total organic carbon was calculated by subtracting total inorganic carbon from total carbon. C:N was calculated with total carbon to total nitrogen. Electrical conductivity (EC), pH and sodium adsorption ratio (SAR) were determined from saturated paste extracts (Carter and Gregorich 2008). Soils with EC > 4 dS m^{-1} are considered saline. Soils with SAR > 13 are considered sodic. Sand, silt and clay were determined by the hydrometer method after treatment with calgon (Carter and Gregorich 2008).

3.4 SOIL TEMPERATURE AND HYDROLOGIC MEASUREMENTS

HOBO micro station data loggers (Onset Computer Corporation, Bourne, MA) with plug in soil volumetric water and temperature smart sensors were installed in late May 2008. Sensors were installed at 5 cm depths in LFH and peat plots, under large and small pieces of *Picea mariana* and *Populus tremuloides* woody debris, and in control plots. Treatment locations were replicated three times and instrumentation was installed in the bottom row of plots on relatively level ground. Data were collected hourly for the duration of the study. Mean weekly volumetric water content and temperature ranges were calculated per treatment location. In early March 2009, an error occurred with one of the soil water sensors in an LFH plot under a large *Populus tremuloides* log; thus, this treatment had two replicates between March and August 2009. A calibration equation was used for volumetric water content for each cover type (Appendix C). O'Kane Consultants Inc. provided equations, based on previous data sets collected on peat and LFH covers and on maximum and minimum values from this study.

3.5 MICROBIAL AND MYCORRHIZAL SAMPLING AND ANALYSES

In August 2008 three soil samples for microbial biomass carbon were collected from 0 to 10 cm depths under each of large and small pieces of *Picea mariana* and *Populus tremuloides* in woody debris plots and in control plots. Samples were composited in the field, double bagged, placed directly on dry ice (-78 ℃), transported on dry ice and stored in a freezer (-20 ℃) until analyzed by chloroform fumigation extraction (Vance et al. 1987) in December 2008.

Roots from three plant species per plot were collected for mycorrhizal biomass determination. Species were *Achillea millefolium* L. (common yarrow), *Geranium bicknellii* Britt. (Bicknell's cranesbill) and *Rubus idaeus* L. (wild red raspberry). Only plants next to woody debris were collected from woody debris plots. Plants were extracted from soil with a garden spade, double bagged, placed directly on dry ice (-78 ℃), transported on dry ice and stored in a freezer (-20 ℃) until analysis between November 2008 and February 2009. Glucosamine content ($C_6H_{13}NO_5$) was determined as modified from procedures of Nilsson and Bjurman (1998), Appuhn et al. (2004) and Appuhn and Joergensen (2006).

3.6 VEGETATION ASSESSMENTS

Three line transects were established vertically in each plot. On each transect, five evenly spaced 1 m^2 quadrats were located. Quadrats were maintained for the duration of the study with no soil or plant samples removed. In July 2008 woody debris canopy and ground cover assessments were conducted to characterize the site. Canopy cover was recorded as a percent looking down over all woody debris; ground cover was recorded as percent ground in direct contact with woody debris. Care was taken to keep woody debris in its original location. The woody root material from salvaged soil in LFH was excluded in woody debris cover assessments, but included for regression analyses.

In July 2008, June 2009 and August 2009 canopy cover was estimated for live vegetation (not including plant overlaps), moss, woody debris by size class, rock, litter and bare ground. Woody debris overlapped by vegetation was included thus cover could be > 100%. Dead vegetation and bark fragments were considered litter; spruce cones were considered fine woody debris. Canopy cover per plant species and moss was estimated and above ground biovolume per plant species was estimated in the second growing season. Cover was estimated in 0.5% increments and values < 0.5% were recorded as trace. Biovolume was estimated at 0.25 L increments and values < 0.25 L were recorded as trace. Only vegetation rooted inside quadrats and runners of *Fragaria* spp. (strawberry) growing in the quadrat were included. Data were used to determine species richness. In July 2008, August 2008, June 2009 and August 2009 woody plant abundance was recorded. Species nomenclature followed Moss (1994).

To determine if woody debris created microsites, proximity of plants to woody debris was assessed on peat with woody debris treatments in June and August 2009. LFH plots were not assessed since vegetation was too dense and microsites created by vegetation could influence results. Plants growing within 10 cm of large or medium size logs or within diameter lengths of small woody debris were considered growing in a woody debris microsite. Woody plant density and plant cover and biovolume by species were recorded and divided into categories of near woody debris (large, medium, small) and away from woody debris.

3.7 STATISTICAL ANALYSES

Since woody debris was fresh and roots were unable to utilize it as a substrate, the proportion of ground available for rooting (available ground) was calculated as: available ground = 100 – (% woody debris cover + % rock cover). Vegetation per available ground was calculated to account for differences between plots. To analyze plant species composition, data were grouped based on morphology, origin and life history strategy (Appendix B.1). Plant group classifications followed Moss (1994). Unknown plants were included in morphology and total groupings. Plants not identified to species (*Carex* and *Salix*) and moss and fungi were excluded from plant origin and species richness analyses. To account for presence, trace values were set to 0.1% for cover and 0.001% for biovolume.

PASW/SPSS 17 statistical software was used for data analyses. Most data were analyzed with two way ANOVA for comparisons and interactions among covers and woody debris treatments. A Shapiro-Wilk test was used for normality and a Levene’s test for equality of variance. Most data failed homogeneity of variance and normal distribution assumptions. Therefore, a Scheirer Ray Hare extension of the Kruskal Wallis test was used as a non parametric equivalent to a two way ANOVA (Sokal and Rohlf 1995). Since this test is conservative (Dytham 2003), significance was determined at $p \leq 0.100$ to increase power (Zar 1999). Significant differences were determined with a Mann-Whitney Rank Sum test.

A three way ANOVA was used to analyze glucosamine content for comparisons and interactions among cover types, woody debris treatments and plant species. Data were analyzed parametrically since a non parametric equivalent does not exist. Data for this test passed normality, but failed homogeneity of variance at $p = 0.031$. Parametric ANOVA is a robust test and variance is assumed sufficient to make this the preferred analysis. Significance for three way ANOVA was determined at $p \leq 0.050$. Three regression analyses were done to analyze the relationship between vegetation per available ground, species richness, and woody plant abundance and woody debris cover. Linear regressions were determined significant at $p \leq 0.050$. To analyze microsite data, proportions of vegetation near and away from woody debris were compared with a t-test. If data had unequal variance a Mann-Whitney Rank Sum test was used. Since both parametric and nonparametric tests produced the same results, only parametric p-values are shown. Significance was determined at $p \leq 0.050$.

4. RESULTS AND DISCUSSION

4.1 SOILS

4.1.1 Peat and LFH Cover Effects on Soil Chemistry

In May 2008 peat had significantly higher concentrations of plant available nitrate ($p < 0.001$) and sulphate ($p = 0.008$), while LFH had significantly more available phosphorus ($p < 0.001$) and potassium ($p < 0.001$) (Table 3.4). Throughout the study, peat remained higher in available sulphate and LFH remained higher in phosphorus and potassium. Nitrate concentration remained numerically higher on peat. Available ammonium was significantly higher on LFH, which could indicate higher nitrogen mineralization and a greater microbial community. MacKenzie and Naeth (2009) found similar results with LFH having higher plant available phosphorus and potassium, but did not analyze inorganic nitrogen (NO_3^- and NH_4^+) during the first growing season and found no significant differences in the second growing season.

Plots were fertilized in July between soil samplings. This is apparent during the first growing season when both covers increased in available nitrate in August (Table 3.4). The increase is not as apparent during the second growing season, possibly due to increased vegetation cover and plant uptake. Phosphorus and potassium were in the fertilizer and generally increased throughout the study.

Peat initially had a significantly higher C:N than LFH ($p < 0.001$) due to its significantly higher organic carbon ($p < 0.001$) (Table 3.4). By the second growing season peat C:N decreased to significantly lower than that of LFH (June 2009 $p < 0.001$, August 2009 $p < 0.001$) due to decreased organic carbon, since total nitrogen remained relatively constant. Total nitrogen fluctuated more on LFH than peat, likely due to higher nutrient use by plants and microorganisms, which were both greater on LFH (Table 3.9 and 3.7). Initially both cover types had low total nitrogen and C:N over 30, indicating more inorganic nitrogen immobilization than mineralization (Stevenson 1986). After sites were fertilized, ratios were between 20 and 30, indicating no net gain or loss of inorganic nitrogen (Stevenson 1986). Thus fertilizer offset losses by nutrient immobilization. Organic carbon and organic matter were significantly greater on peat throughout most of the study. Mackenzie (2006) found similar results with peat having significantly greater organic carbon, organic matter and C:N than LFH.

All treatments had sandy loam, sandy clay loam or loam textures. There was no difference in sand, but LFH had more silt ($p < 0.001$) and peat had more clay ($p < 0.001$) (Table 3.4). Means were not biologically significant. Peat had a slightly basic pH and LFH was slightly acidic. EC and SAR were greater on peat than LFH (Table 3.4), but low enough to be classified as good according to Alberta Tier 1 guidelines (Alberta Environmental Protection 1994).

4.1.2 Woody Debris Effects on Soil Chemistry

No soil chemical property differences were found among *Populus tremuloides*, *Picea mariana* and control treatments during May of the first growing season, suggesting woody debris had little immediate effect (Table 3.5). By August and after fertilization, available nitrate was significantly greater in controls than under large *Populus tremuloides* ($p = 0.024$) and *Picea mariana* ($p = 0.011$) logs. Available nitrate increased in all treatments between May and August 2008, likely due to fertilization. In June 2009 available nitrate was significantly higher in controls than under large *Picea mariana* logs ($p = 0.003$), which had the lowest concentrations. Nitrate was significantly higher under large ($p = 0.021$) and small ($p = 0.044$) *Populus tremuloides* than under large *Picea mariana logs*. Controls had numerically highest available nitrate throughout the study (Table 3.5).

Higher nitrate concentrations in controls are likely influenced by fertilization and nitrogen immobilization by wood decomposers. Plots were fertilized in July of each growing season. Woody debris plot samples were collected under woody debris, whereas control samples were collected away from woody debris and without aerial obstruction. Thus either fertilizer accumulated less under large logs due to vertical obstruction or it accumulated more under woody debris due to runoff caught by logs creating horizontal obstruction on the soil surface.

Several studies have shown nitrogen immobilization caused by microbial decomposers of woody debris. Mycelial cord forming saprotrophic fungi can translocate nutrients from soil into woody debris to aid decomposition (Wells and Boddy 1990). Zimmerman et al. (1995) and Kayahara et al. (1996) found forest soils with woody debris had lower nitrogen concentrations. Other studies showed nitrogen increasing in woody debris over time (Harmon et al. 1986, Sinsabaugh et al. 1993, Laiho and Prescott 1999, Krankina et al. 1999). How quickly saprotrophic decomposing fungi can translocate nutrients on highly disturbed landscapes is unknown. Cover soil collection, transportation and placement likely caused senescence of soil fungi. Woody debris was alive when cut and placed on the site shortly after. Woody debris begins decomposition while standing as decomposing fungi occupy the tree when it begins to die (Boddy 2001). Fungal propagules are latently present in sapwood and are unable to develop until high water stress in functioning sapwood is reduced (Boddy 2001).

Spores can reach woody debris by wind, water or animals. Their successful establishment depends on finding local favourable growing conditions. This might have been an issue for logs in this study. Logs placed on site were not under a forest canopy, thus temperature and moisture might not have been optimal for fungal establishment and decomposition might be slowed. Substrate quality and environment strongly influence woody material decay rates (Laiho and Prescott 2004) and log moisture status is positively correlated to decomposition (Brown et al. 1995). Although fungal colonization of woody debris was not assessed in this study observations were noted. In August 2008, holes were observed in *Picea mariana* logs, likely produced by beetles, which would provide fungi with an easy path to interior wood (Siitonen 2001). In August 2008 and 2009, the fruiting body of *Ischnoderma resinosum* (Fr.) Karst, a common wood decomposing fungi, was found growing on sides of *Populus tremuloides* and *Picea mariana* logs and a white rot fungi was observed growing under logs.

Woody debris can have different effects on available phosphorus during stages of decay. Throughout decay, microbial decomposers can immobilize phosphorus in woody debris and decrease soil concentrations (Wells and Boddy 1990, Sinsabaugh et al. 1993, Kayahara et al. 1996, Laiho and Prescott 1999). During early stages of decay, leachate from fresh woody debris is high in phosphorus and can increase soil concentrations (Auerswald and Weigand 1996; Kuehne et al. 2008). Woody debris releases phosphorus in soil while nutrient rich bark is still intact and immobilizes phosphorus during later decay stages (Krankina et al. 1999). Since woody debris in this study was fresh, soil under woody debris could be higher in phosphorus than soil in controls. Although no significant differences were found among woody debris treatments (Table 3.5), after initial soil collection, controls had the lowest available phosphorus throughout the remainder of the study. Since phosphorus and nitrogen were added in fertilizer and phosphorus and nitrate show opposite trends, results are likely not just caused by fertilization. Some nitrogen immobilization and phosphorus leaching appears to be occurring; however the extent was not determined.

No significant differences existed between woody debris treatments for available ammonium, potassium and sulphate (Table 3.5). Similarly, no differences were found between treatments in C:N, total organic carbon, total nitrogen, total organic matter, electrical conductivity or sodium adsorption ratio (Table 3.6). Thus either woody debris had little effect on these parameters, or requires more time for effects to become apparent.

4.1.3 Cover Treatment Effects on Soil Temperature and Water

Within LFH treatments, soil weekly temperature range under large *Populus tremuloides* and *Picea mariana* logs was lower than controls (Figure 3.2a). In June and July 2008, soil weekly temperature range under large logs was about 2 ℃ less than controls. Effects of woody debris became more apparent by May 2009, when temperature range was highest in controls, followed by small pieces of woody debris, large *Picea mariana* logs and large *Populus tremuloides* logs. At that time temperature range under large logs was about 3 ℃ less than controls.

A similar and stronger trend was found in peat (Figure 3.2b). Soil weekly temperature range under large *Populus tremuloides* logs was lower than all other treatments, followed by large *Picea mariana* logs. This likely resulted from woody debris size since large *Populus tremuloides* logs were larger than large *Picea mariana* logs. During the second growing season, controls consistently had highest weekly temperature ranges. Soil temperature range under large *Picea mariana* logs was about 5 ℃ less than controls and that under large *Populus tremuloides* logs was about 7 ℃ less than controls.

Peat had higher volumetric water content than LFH throughout the study (Figure 3.3). LFH controls had lowest weekly water content (m^3/m^3) throughout the study (Figure 3.3a). No trend existed between woody debris species or size treatments, suggesting presence and not size affected soil volumetric water on LFH. Peat under small woody debris generally had higher volumetric water than peat under large woody debris; water content on controls varied from highest to lowest (Figure 3.3b). Differences between covers might be due to higher organic matter in peat (Table 3.4). Peat controls peaked earlier and higher than LFH and woody debris treatments during snow melt. Woody debris likely acted as a barrier between snow and soil surface reducing infiltration under logs and snow on woody debris plots may have melted at a slower rate. Water contents decreased in winter since sensors record free water in soil pores, not ice.

Early succession sites often have extreme fluctuations in soil temperature and intense radiation, leading to elevated rates of evaporation and drying of the soil surface and creating a stressful environment for vegetation. Protection against water loss and seed desiccation is important for germination and establishment (Harper et al. 1965, Sheldon 1974, Hamrick and Lee 1987, Jumpponen et al. 1999). Areas near and under large woody debris pieces were exposed to muted temperature extremes and elevated soil water. This effect is important in oil sands disturbances where protection from harsh environmental conditions is limited and a favourable microclimate is necessary for seed germination.

4.1.4 Cover Treatment Effects on Soil Microbial Biomass Carbon

LFH had significantly higher soil microbial biomass carbon than peat ($p < 0.001$) (Table 3.7), with values four times greater. McMillan et al. (2007) did a similar comparison on four to five year old reclaimed sites and found similar results with LFH treatments having 1.4 times more microbial biomass carbon than peat treatments. As their reclaimed sites had longer to develop, LFH was 8.8 times greater and peat was 26 times greater than in this study. They found reclaimed sites had significantly lower microbial biomass carbon than undisturbed sites. Several studies found microbial communities decreased after anthropogenic disturbance (Atlas et al. 1991, Peacock et al. 2001, McMillan et al. 2007).

Soil biomass carbon did not differ between treatments with and without woody debris (Table 3.7). Since samples were collected in the first growing season, more time may be needed to quantify differences and this study supplies baseline data for future studies. Woody debris may affect the microbial community that develops. Fungi are the main decomposers of woody organic material and are expected to increase with woody debris, creating a greater fungal bacterial ratio with time (Brant et al. 2006). Fungal biomass contributes large amounts of available nutrients to the soil and its turnover greatly influences carbon and nutrient cycling (Miller and Lodge 2007).

4.1.5 Cover Treatment Effects on Root Glucosamine

Roots in LFH had significantly more glucosamine per root than those in peat (Table 3.7 $p = 0.028$). LFH had greater mycorrhizal biomass than peat. Values were not compared to undisturbed, but mycorrhizae are known to be sensitive to anthropogenic disturbances (Allen and Friese 1992). This study shows that if soil is directly placed and not stockpiled, mycorrhizae can develop during the first growing season. There was a significant difference among plant species ($p = 0.005$) with *Rubus idaeus* and *Achillea millefolium* having significantly more glucosamine than *Geranium bicknellii* (Table 3.8). *Rubus idaeus* had the most mycorrhizae and *Geranium bicknellii* had the least, likely since it is a biennial.

Root glucosamine did not differ with woody debris treatment. Either woody debris will increase mycorrhizae since it provides a more favourable environment for roots or woody debris will decrease mycorrhizal associations due to competition with saprotrophic fungi. Vogt et al. (1995) found vegetation in sloughed bark fragments or on woody debris in forest canopy gaps had greater mycorrhizal diversity. Woody fragments helped sustain mycorrhizae after disturbance, likely because it provided microsites with a more favourable growing environment. Lindahl et al. (2001) compared competitive abilities between mycorrhizal fungi and saprotrophic fungi on two different sized wood blocks. Saprotrophic fungi on large blocks (1.6 cm^3) outcompeted mycorrhizae for nutrients, but fungi on small blocks (0.44 cm^3) did not outcompete mycorrhizae. Fungi that were outcompeted grew less mycelium. Results suggest saprotrophic fungi will have a competitive advantage when growing in areas with sufficient nutrients and energy and may have a competitive advantage on this site, especially during early stages of decay when nutrient supplies in logs have not been depleted.

4.2 VEGETATION

4.2.1 Cover Treatment Effects on Canopy Cover

LFH consistently had significantly greater vegetation canopy cover than peat, significantly less bare ground and greater vegetation cover per available ground (Table 3.9). Similarly, MacKenzie and Naeth (2007) found LFH had significantly greater canopy cover than peat.

Vegetation canopy cover did not differ significantly between treatments with and without woody debris (Table 3.9). During the first growing season, controls had significantly more bare ground than *Populus tremuloides* (p = 0.018) and *Picea mariana* treatments (p < 0.001) (Table 3.9). *Populus tremuloides* treatments had significantly more bare ground than *Picea mariana* treatments (p = 0.024) due to woody debris (Table 3.1). Differences continued through June 2009, with controls having significantly more bare ground than *Picea mariana* treatments (p = 0.011), and *Populus tremuloides* treatments (p = 0.057). No significant differences were found in August 2009, but controls had the most bare ground.

Vegetation per available ground was not significantly different with treatments throughout the study (Table 3.9). *Picea mariana* treatments had highest cover throughout the study followed by *Populus tremuloides* treatments. During the first growing season, five of six control plots with peat had vegetation covers < 1% and one plot had > 21% due to introduced annual *Chenopodium album* L.

Regression analyses to determine the relationship between vegetation cover per available ground and woody debris cover in each cover type was not significant in 2008 (Figure 3.4a,b), indicating woody logs had no immediate effect on vegetation establishment. However, in June of the second growing season significant positive relationships existed on LFH (Figure 3.4c; p = 0.004) and peat (Figure 3.4d; p = 0.047). At the end of that growing season, a significant positive relationship existed for LFH (Figure 3.4e; p = 0.005), but not for peat (Figure 3.4f). Results suggest woody debris aids post winter survival. In June 2009, introduced annual species were beginning to grow. By August, introduced annual species, such as *Chenopodium album,* were much larger and contributed more cover, especially in peat which had a lower vegetation cover than LFH. The higher vegetation cover on LFH likely suppressed growth of introduced annual species. Peat had a lower cover and more room for introduced annual species, thus the relationship was no longer significant once they grew larger.

4.2.2 Peat and LFH Cover Effects on Plant Group Cover and Biovolume

LFH had significantly higher canopy cover of forbs, grasses, sedges and woody species throughout the study (Table 3.10). Peat had significantly greater canopy cover of pteridophytes. Biovolume followed the same trend (Table 3.11). Peat had significantly higher moss cover in June 2009, but values were low. In August 2009, moss cover was higher and significantly greater on LFH. Moss prefers growing under vegetation, likely due to lower temperatures and levels of radiation experienced under denser vegetation canopies (Maestre et al. 2002). LFH had significantly more vegetation cover throughout the study and in August 2009, almost twice that recorded on peat (Tables 3.9, 3.10). The higher vegetation cover on LFH likely provided moss with a more favourable growing environment.

LFH had greater cover of annual, biennial and perennial species throughout the study (Table 3.10). During the first growing season, LFH and peat had mostly annual and biennial species, due to quick emergence *Potentilla norvegica* L., *Corydalis aurea* Willd. and *Geranium bicknellii* Britt. Over time, LFH had more perennial species and during the second growing season most species were perennial. Peat had mainly annual and biennial species throughout both growth seasons. Similar trends were found for biovolume (Table 3.11).

LFH had significantly greater native species cover throughout the study (Table 3.10). LFH had significantly greater introduced species cover during the first growing season, but significantly less during the second (Table 3.10). LFH had greater cover of introduced species during the first growing season, but peat had a greater proportion which continued throughout the study. Biovolume showed similar trends (Table 3.11). In July 2008 the main introduced species were *Chenopodium album* and *Crepis tectorum* L. In June 2009, they were still dominant, but *Chenopodium album* was very small. This time had the lowest introduced species cover (Table 3.10). By August 2009, introduced species had spread and grown, contributing more cover. Other introduced species such as *Kochia scoparia* L. Schrad., *Melilotus alba* Desr. and *Salsola kali* L. appeared.

4.2.3 Woody Debris Effects on Plant Group Cover and Biovolume

Few significant differences in canopy cover and biovolume occurred with and without woody debris (Tables 3.12, 3.13 and 3.14). *Picea mariana* treatments had significantly greater moss cover than controls in July 2008 (Table 3.12; p = 0.005) and June 2009 (Table 3.13; p = 0.010). In June 2009 *Picea mariana* treatments had significantly more moss cover than *Populus tremuloides* treatments (Table 3.13; p = 0.017). Moss prefers to grow in moist environments, suggesting *Picea mariana* treatments provided more favourable habitat due to greater cover of woody debris (Table 3.1). There was a significant difference in introduced species cover in June 2009 (p = 0.014) with *Picea mariana* having greatest cover (Table 3.13). *Crepis tectorum* was abundant around the sides of logs, which likely trapped the wind dispersed seeds. By August 2009 controls had the most cover and biovolume of introduced species (Table 3.14). *Chenopodium album* had grown and contributed more cover than *Crepis tectorum*. *Chenopodium album* does not have wind dispersed seeds and is likely less affected by woody debris. Cover and biovolume of woody species were numerically highest on *Picea mariana* treatments throughout the study (Tables 3.12, 3.13 and 3.14).

4.2.4 Cover Treatment Effects on Species Richness

LFH had significantly greater species richness and native species richness than peat throughout the study (Table 3.15). The difference is small with total species on each cover treatment (Table 3.3). MacKenzie (2006) found similar results with LFH having greater species richness and diversity than peat. No significant differences existed between woody debris treatments throughout this study (Table 3.15). *Picea mariana* treatments had the greatest numerical species richness throughout the study. *Populus tremuloides* treatments and controls had similar species richness, except during June 2009 when *Populus tremuloides* treatments were higher. Total species richness throughout the study was highest in *Picea mariana* treatments and lowest in controls (Table 3.3).

Regression analyses to determine the relationship between species richness and woody debris cover was significantly positive in June 2009 ($p = 0.003$), but not July 2008 or August 2009 (Figure 3.5). June 2009 vegetation survived the winter, suggesting woody debris aids survival during harsh environmental conditions.

Based on the regeneration niche theory introduced by Grubb (1977), plots with woody debris were expected to have greater species richness. This theory assumes plant species have different requirements to survive and grow. Increasing habitats on a landscape should increase species richness. Generally, reclaimed landscapes in the oil sands are flat and homogeneous. Few microsites are available to protect seedlings from climatic and biotic stressors. Adding woody debris increases landscape heterogeneity and should increase species richness. Woody debris attracted birds (personal observation), which act as a seed dispersal agent and could lead to greater species richness. Microsites, or safe sites, can allow greater opportunity for cohabitation (Harper et al. 1961), increasing species evenness and not allowing one or a few species to dominate. Although not significant, these trends were observed on *Picea mariana* woody debris treatments, which had greater woody debris cover than *Populus tremuloides* treatments (Tables 3.1 and 3.2).

4.2.5 Cover Treatment Effects on Woody Plant Abundance

LFH had significantly greater woody plant abundance than peat during the first growing season (July 2008 $p < 0.001$; August 2008 $p = 0.010$) but not during the second (Table 3.16). Significant differences were found between woody debris treatments in August 2008 ($p = 0.002$), June 2009 ($p = 0.001$) and August 2009 ($p = 0.001$). *Picea mariana* woody debris had greatest abundance of woody plants throughout the study and controls had the lowest during the second growing season (Table 3.16). *Picea mariana* woody debris acted as a propagule source and contained cones which produced viable saplings. *Picea mariana* are difficult to grow in oil sands reclaimed areas. Planted saplings live their first couple years in a green house with favourable conditions. They are transplanted in reclaimed areas and have trouble surviving due to intense radiation and temperature fluctuations. This is especially true for *Picea mariana*, which generally resides in low lying bogs and fens. Saplings grown from cones on site may have a better chance of surviving since conditions select the fittest seeds able to grow in the harsh early succession conditions. *Picea mariana* treatments had the greatest number of woody plants even without *Picea mariana* saplings.

Regression analysis found a significant positive relationship between woody plant abundance and woody debris cover in August 2008 ($p < 0.001$), June 2009 ($p < 0.001$) and August 2009 ($p = 0.001$) (Figure 3.6). Lack of a significant relationship in July 2008 suggests woody debris did not influence initial emergence. Seeds in the seed bank likely grew once adequate water and light were available. Woody debris likely affected sapling survival by providing microsites protecting against unfavourable conditions. Oil sands reclamation sites tend to be open with limited ground cover. Thus saplings are exposed to wind, temperature extremes and other variable abiotic and biotic factors as they attempt to survive and grow. Microsites created by woody debris likely ameliorate conditions to aid sapling survival. Similar studies have found sapling abundance positively associated with coarse woody debris in forest canopy gaps (Grey and Spies 1997, Beach and Halpern 2001). Other studies found higher seedling densities in microsites on recessional moraines undergoing primary succession (Jumpponen et al. 1999; Jones and del Moral 2005)**.**

4.2.6 Cover Treatment Effect Microsites

Proximity of vegetation to woody debris showed significantly more vegetation grew near woody debris during June 2009 but not August 2009 (Table 3.17). In June 2009 significantly more vascular plants ($p < 0.001$), moss ($p = 0.001$), total vegetation ($p < 0.001$) and introduced species ($p < 0.001$) grew in close proximity to woody debris. A numerically greater proportion of native species were growing near woody debris. Similar results were found with biovolume ($p = 0.001$) and introduced biovolume ($p < 0.001$) near woody debris. Cover and biovolume of introduced species were likely greater near woody debris because *Crepis* *tectorum* was the most abundant introduced species in June 2009. *Crepis tectorum* has a wind dispersed seed and accumulated along sides of woody logs. Wind dispersed seeds tend to establish more where seeds can become trapped by soil surface heterogeneity (Sheldon 1974), such as near rocks and in depressions (Jumpponen et al. 1999, Jones and del Moral 2005).

By August 2009 only moss cover was significantly greater near woody debris ($p < 0.001$) and introduced species cover was significantly greater away from woody debris ($p = 0.002$) (Table 3.17). The switch in introduced species was likely caused by *Chenopodium album*, which grew wherever space was available and did not require microsites for protection. Total cover and biovolume proportions were no longer significant, likely due to outward movement and microsites created by other vegetation (Fowler 1988, Oswald and Neuenschwander 1993, Jones and del Moral 2005). Vegetation cover can decrease soil temperature extremes and evaporation, making seedling germination less dependent on structural microsites (Jones and del Moral 2005). Moss cover remained significant throughout the study suggesting woody debris creates a more favourable microsite for moss and a heavier cover of vascular vegetation is needed for moss to extend from woody debris.

Although non woody vegetation spread from woody debris during the second growing season, a significantly greater proportion of woody species remained close to woody debris in June ($p < 0.001$) and August 2009 ($p < 0.001$) (Table 3.17). Trends continued with woody plant cover ($p < 0.001$; $p < 0.001$) and biovolume ($p = 0.005$; $p = 0.002$) significant during both assessments. *Salix* species were the most abundant woody plants and significantly more abundant close to woody debris during both assessments ($p < 0.001$; $p < 0.001$). Over 80% of *Salix* were found near woody debris. *Salix* are wetland species, suggesting areas close to woody debris provide a wetter, more favourable environment. Woody debris likely aids survival, resulting in more woody plants near microsites.

Although microsites on control plots were not assessed some trends were observed. In June 2009 most vegetation on controls was located in microsites of erosion rills or cracks in the soil surface. Peat had large areas of bare ground (Table 3.9), much of which had a crust. Soil crusts can be formed by heavy rain that initiates runoff and causes fine particles to flow into pores in the soil surface, producing a cemented seal (McIntyre 1958). Shrinking and swelling of clays contribute to the process and cracks can form in the soil surface. The most abundant species in these areas include *Crepis tectorum*, *Chenopodium album* and *Equisetum arvense* L. *Crepis tectorum* has wind dispersed seeds able to lodge in the soil cracks (Sheldon 1974). *Chenopodium album* has gravity dispersed seeds, likely carried by surface runoff until they stopped in a surface crack or erosion rill. *Equisetum arvense* is a weed species that prefers wetter soils, suggesting erosion rills and soil cracks were better protected against desiccation. Other studies provided similar reasoning (Harper et al. 1965, Jumpponen et al. 1999, Jones and del Moral 2005). In oil sands reclamation, peat is seeded to a cover crop of *Hordeum vulgare* L. (common barley) to prevent erosion and surface crust (Oil Sands Revegetation Reclamation Committee 1998). Soil erosion and surface crusting are less problematic on LFH due to greater soil surface heterogeneity from fine root debris.

5. SUMMARY

Differences between LFH and peat covers

- LFH had significantly more available phosphorus, potassium and ammonium throughout the study. Peat had significantly more available sulphur throughout the study and significantly more available nitrate initially.
- C:N was greater on peat during the first growing season and greater on LFH the second growing season. Peat generally had significantly more total organic matter, total organic carbon and total nitrogen.
- LFH was slightly acidic and peat was slightly basic. Peat had a significantly higher EC and SAR, but values were low.
- Peat had greater volumetric water content than LFH, likely due to higher organic matter content.
- LFH had significantly greater microbial biomass carbon and mycorrhizal biomass.
- LFH had significantly greater vegetation cover, biovolume and species richness. LFH had significantly greater cover and biovolume of forbs, grasses, sedges, woody species, annual/biennial, perennial and native species. Peat

had significantly greater cover of pteridophytes and initially more moss cover. LFH had significantly more moss cover by the end of the study. Initially LFH had significantly more introduced species cover and biovolume, but peat had significantly more by the second growing season. Peat had a greater proportion of introduced species cover throughout the study.

- LFH had a greater abundance of woody plants, but differences were only significant during the first growing season, after which woody debris had a greater influence on woody plant abundance.

Differences between woody debris treatments

- Soil in controls had the greatest available nitrate throughout the study, at times significantly greater than soil under large woody debris. Low available nitrate under woody logs could indicate nutrient immobilization. Available phosphorus was lowest on controls throughout the study, supporting other findings that leachate from woody debris is high in phosphorus.
- There were no differences between woody debris treatments in sulphur, potassium, ammonium, C:N, total organic matter, total organic carbon, total nitrogen, SAR, EC and pH.
- Control soils had the largest temperature ranges; soil under large woody debris had the smallest.
- Soil under woody debris on LFH had greater volumetric water content than controls. Woody debris did not affect soil water on peat covers, likely due to higher organic matter content.
- After one growing season, woody debris and size did not affect soil microbial biomass carbon and mycorrhizal biomass.
- A positive relationship was found between woody debris cover and vegetation cover per available ground in June 2009. The relationship continued during August 2009 on LFH but not on peat.
- A positive association was found between woody debris and species richness in June 2009.
- Woody debris had significantly greater abundance of woody plants throughout the study. A positive relationship was found between woody debris cover and woody plant abundance throughout the study. *Picea mariana* woody debris acted as a seed source for *Picea mariana* saplings.

- In June 2009 most vegetation on peat grew close to woody debris. Vegetation spread from woody debris microsites by August 2009. A greater proportion of woody plant abundance and cover was found close to woody debris throughout the second growing season.
- Microsites created by woody debris aided vegetation survival during early succession.

6. CONCLUSIONS

This research shows the value of woody debris in a reclaimed landscape. Woody debris on LFH or peat covers facilitated reclamation by providing microsites with favourable growing conditions. Soil under woody debris had muted temperature extremes and higher water contents. Woody plants were more abundant in close proximity to woody debris and abundance was positively associated with woody debris cover. *Picea mariana* woody debris was a source of viable *Picea mariana* propagules, which is often a difficult species to grow in reclaimed areas. Woody debris cover was positively associated with species richness and vegetation cover per available ground. Benefits of woody debris microsites need to be balanced with potential detrimental effects of nutrient immobilization.

7. LITERATURE CITED

Alberta Environmental Protection. 1994. Draft Alberta tier I criteria for contaminated soil assessment and remediation. Alberta Environmental Protection, Edmonton, Alberta. 196 pp.

Allen, M.F. and C.F. Friese. 1992. Mycorrhizae and reclamation success: importance and measurement. In: Evaluating Reclamation Success: The Ecological Consideration. Proceedings of a Symposium. April 23-26, 1990 United States Department of Agriculture. Charleston, West Virginia. Pp. 17-25.

Appuhn, A. and R.G. Joergensen. 2006. Microbial colonization as a function of plant species. Soil Biology & Biochemistry 38:1040-1051.

Appuhn, A. R.G. Joergensen, M. Raubuch, E. Scheller and B. Wilke. 2004. The automated determination of glucosamine, galactosamine, muramic acid, and mannosamine in soil and root hydrolysates by HPLC. Journal of Plant Nutrition and Soil Science 167:17-21.

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

Atlas, R.M., A. Horowitz, M. Krichevsky and A.K. Bej. 1991. Response of microbial populations to environmental disturbance. Microbial Ecology. 22(1):249-256.

Auerswald, K. and S. Weigand. 1996. Ecological impact of dead-wood hedges; release of dissolved phosphorus and organic matter into runoff. Ecological Engineering 7:183-189.

Beach, E.W. and C.B. Halpern. 2001. Controls on conifer regeneration in managed riparian forests: effects of seed source, substrate, and vegetation. Canadian Journal of Forest Research 31:471-482.

Boddy, L. 2001. Fungal community ecology and wood decomposition processes in angiosperms: from standing tree to complete decay of coarse woody debris. Ecological Bulletins 49:43-56.

Brant, J.B., E.W. Sulzman and D.D. Myrold. 2006. Microbial community utilization of added carbon substrates in response to long-term carbon input manipulation. Soil Biology & Biochemistry 38:2219-2232.

Bremner, J.M. 1996. Nitrogen-total (Dumas methods). In: J.M. Bartels (ed.). Methods of soil analysis: part 3 chemical methods. (3rd ed.). American Society of Agronomy, Inc. and Soil Science Society of America. Madison, WI, USA. Book series no. 5. 1088 pp.

Brennan, K.E.C., O.G. Nichols and J.D. Majer. 2005. Innovative techniques for promoting faunal return to rehabilitated sites following mining. Australian Centre for Minerals Extension and Research (ACMER), Brisbane and Minerals and Energy Research Institute of Western Australia (MERIWA Report 248). Perth, Australia. 123 pp.

Brown, S., J. Mo, J.K. McPherson and D.T. Bell. 1995. Decomposition of woody debris in Western Australian forests. Canadian Journal of Forest Research 26:954-966.

Carlyle, J.C., M.W. Bligh and E.K. Sadanandan Nambiar. 1998. Woody residue management to reduce nitrogen and phosphorus leaching from sand soil after clear-felling *Pinus radiate* plantations. Canadian Journal of Forest Research 28:1222-1232.

Carter, M.R. and E.G. Gregorich. 2008. Soil sampling and methods of analysis (2nd ed.). Canadian Society of Soil Science. Taylor & Francis Group. Florida, USA.

Christy, E.J. and R.N. Mack. 1984. Variation in demography of juvenile *Tsuga heterophylla* across the substratum mosaic. The Journal of Ecology 72(1):75-91.

Debeljak, M. 2006. Coarse woody debris in virgin and managed forest. Ecological Indicators 6:733-742.

DePuit, E.J. 1984. Potential topsoiling strategies for enhancement of vegetation diversity on mined lands. Minerals and the Environment 6:115-120.

Dytham, C. 2003. Choosing and using statistics: a biologist's guide. (2nd ed.). Blackwell Publishing. Oxford, UK. 266 pp.

Environment Canada. 2003. Canadian climate normals 1971 - 2000. http://www.climate.weatheroffice.ec.gc.ca/climate_normals/results_e.html. accessed April 2009. Meteorological Service of Canada, Environment Canada, Government of Canada.

Fowler, N.L. 1988. What is a safe site?: neighbour, litter, germination date, and patch effects. Ecology 69(4):947-961.

Government of Alberta. 2009. Environmental management of Alberta's oil sands: resourceful. Responsible. Government of Alberta, Canada. 24 pp.

Graham, S.A. 1925. The felled tree trunk as an ecological unit. Ecology 6(4):397-411.

Grey, A.N. and T.A. Spies. 1997. Microsite controls on tree seedling establishment in conifer forest canopy gaps. Ecology 78(8): 2458-2473.

Grubb, P.J. 1977. The maintenance of species-richness in plant communities: the importance of the regeneration niche. Biological Reviews 52(1):107-145.

Hafner, S.D., P.M. Groffman and M.J. Mitchell. 2005. Leaching of dissolved organic carbon, dissolved organic nitrogen, and other solutes from coarse woody debris and litter in a mixed forest in New York state. Biogeochemistry 74:257-282.

Hamrick, J.T. and J.M. Lee. 1987. Effect of soil surface topography and litter cover on the germination, survival, and growth of musk thistle (*Carduus nutans*). American Journal of Botany 74(3):451-457.

Harmon, M.E., J.F. Franklin, F.J. Swanson, P. Sollins, S.V. Gregory, J.D. Lattin, N.H. Anderson, S.P. Cline, N.G. Aumen, J.R.Sedell, G.W. LienKaemper, K. Cromack Jr. and K.W. Cummins. 1986. Ecology of coarse woody debris in temperate ecosystems. Advances in Ecological Research 15:133-302.

Harmon, M.E. and C. Hua. 1991. Coarse woody debris dynamics in two old-growth ecosystems. BioScience 41(9):604-610.

Harper, J.L., J.N. Clatworthy, I.H. McNaughton and G.R. Sagar. 1961. The evolution and ecology of closely related species living in the same area. Evolution 15(2):209-227.

Harper, J.L., J.T. Williams and G.R. Sagar. 1965. The behaviour of seeds in soil: I. The heterogeneity of soil surfaces and its role in determining the establishment of plants from seed. Journal of Ecology 53(2):273-286.

Hicks, W.T., M.E. Harmon and D.D. Myrold. 2003. Substrate controls on nitrogen fixation and respiration in woody debris from the Pacific Northwest, USA. Forest Ecology and Management 176:25-35.

Hofgaard, A. 1993. 50 years of change in a Swedish boreal old-growth *Picea abies* forest. Journal of Vegetation Science 4(6):773-782.

Jones, C.C. and R. del Moral. 2005. Effects of microsite conditions on seedling establishment on the foreland of Coleman Glacier, Washington. Journal of Vegetation Science 16:293-300.

Jumpponen, A., H. Vare, K.G. Mattson, R. Ohtonen and J.M. Trappe. 1999. Characterization of ‘safe sites’ for pioneers in primary succession on recently deglaciated terrain. Journal of Ecology 87(1):98-105.

Kayahara, G.J., K. Klinka and L.M. Lavkulich. 1996. Effects of decaying wood on eluviation, podzolization, acidification, and nutrition in soils with different moisture regimes. Environmental Monitoring and Assessment. 39:485-492.

Krankina, O.N., M.E. Harmon and A.V. Griazkin. 1999. Nutrient stores and dynamics of woody detritus in a boreal forest: modeling potential implications at the stand level. Canadian Journal of Forest Research 29:20-32.

Kuehne, C., C. Donath, S.I. Muller-Using and N. Bartsch. 2008. Nutrient fluxes via leaching from coarse woody debris in a Fagus sylvatica forest in the Solling Mountains, Germany. Canadian Journal of Forest Research 38:2405-2413.

Laiho, R. And C.E. Prescott. 2004. Decay and nutrient dynamics of coarse woody debris in northern coniferous forests: a synthesis. Canadian Journal of Forest Research 34:763-777.

Laiho, R. and C.E. Prescott. 1999. The contribution of coarse woody debris to carbon, nitrogen, and phosphorus cycles in three Rocky Mountain coniferous forests. Canadian Journal of Forest Research 29:1592-1603.

Lindahl, B., J. Stenlid and R. Finlay. 2001. Effects of resource availability on mycelial interactions and ^{32}P transfer between saprotrophic and an Ectomycorrhizal fungus in soil microcosms. FEMS Microbiology Ecology 38:43-52.

Loeppert, R.H. and D.L. Suarez. 1996. Gravimetric method for loss of carbon dioxide. In: J.M. Bartels (ed.). Methods of soil analysis: part 3 chemical methods. (3rd ed.). American Society of Agronomy, Inc. and Soil Science Society of America. Madison, WI, USA. Book series no. 5. Pp. 455-456.

MacKenzie, D.D. and M.A. Naeth. 2009. The role of the forest soil propagule bank in assisted natural recovery after oil sands mining. Restoration Ecology Online Archives.

MacKenzie, D.D. and M.A. Naeth. 2007. Assisted natural recovery using a forest soil propagule bank in the Athabasca Oil Sands. Seeds: Biology, Development and Ecology. Pp. 374-382.

MacKenzie, D.D. 2006. Assisted natural recovery using a forest soil propagule bank in the Athabasca Oil Sands. M.Sc. Thesis. Department of Renewable Resources, University of Alberta. Edmonton, Alberta. 151 pp.

Maestre, F.T., M. Huesca, E. Zaady, S. Bautista and J. Cortina. 2002. Infiltration, penetration resistance, and microphytic crust composition in contrasted microsites within a Mediterranean semi-arid steepe. Soil Biology & Biochemistry 34:895-898.

McIntyre, D.S. 1958. Soil splash and the formation of surface crusts by raindrop impact. Soil Science 85:261-266.

McKeague, J.A.. 1978. Manual on soil sampling and methods of analysis. Canadian Society of Soil Science. Ottawa, Ontario. 212 pp.

McMillan, R., S.A. Quideau, M.D. MacKenzie and O. Biryukova. Nitrogen mineralization and microbial activity in oil sands reclaimed boreal forest soils. Journal of Environmental Quality 36:1470-1478.

Miller, R.M. and D.J. Lodge. 2007. 4 fungal responses to disturbance: agriculture and forestry. In: C.P. Kubicek and I.S. Druzhinina (eds.). Environmental and Microbial Relationships. (2nd ed.). Springer-Verlag Berlin Heidelberg.

Moss. E.H. 1994. Flora of Alberta: a manual of flowering plants, conifers, ferns and fern allies found growing without cultivation in the province of Alberta, Canada. University of Toronto Press. Toronto, Ontario. 687 pp.

National Energy Board. 2000. Canada’s oil sands: a supply and market outlook to 2015. An Energy Market Assessment. Calgary, Alberta. 121 pp.

Natural Regions Committee. 2006. Natural regions and subregions of Alberta. Compiled by D.J. Downing and W.W. Pettapiece. Government of Alberta. Pub. No. T/852.

Nelson, D.W. and L.E. Sommers. 1996. Total carbon, organic carbon, and organic matter. In: J.M. Bartels (ed.). Methods of Soil Analysis: Part 3 Chemical Methods. (3rd ed.). American Society of Agronomy, Inc. and Soil Science Society of America. Madison, WI, USA. Book series no. 5. Pp. 961-1010.

Nilsson, K. and J. Bjurman. 1998. Chitin as an indicator of biomass of two wood-decay fungi in relation to temperature, incubation time, and media composition. Canadian Journal or Microbiology 44:575-581.

Oil Sands Revegetation Reclamation Committee. 1998. Guidelines to reclamation to forest vegetation in the Athabasca Oil Sands Region. Fort

McMurray, Alberta. 212 pp.

Oswald, B.P. and L.F. Neuenschwander. 1993. Microsite variability and safe site description for western larch germination and establishment. Bulletin of the Torrey Botanical Club 120(2):148-156.

Peacock, A.D., S.J. Macnaughton, J.M. Cantu, V.H. Dale and D.C. White. 2001. Soil microbial biomass and community composition along an anthropogenic disturbance gradient within a long-leaf pine habitat. Ecological Indicators 1:113-121.

Pyle, C. and M.M. Brown. 1999. Heterogeneity of wood decay classes with hardwood logs. Forest Ecology and Management 144:253-259.

Sheldon, J.C. 1974. The behaviour of seeds in soil: III. The influence of seed morphology and the behaviour of seedlings on the establishment of plants from surface-lying seeds. Journal of Ecology 62(1):47-66.

Siitonen, J. 2001. Forest management, coarse woody debris and saproxylic organisms: Fennoscandian boreal forests as an example. Ecological Bulletins 49:11-41.

Singh, K. 2007. Approval: province of Alberta, environmental protection and enhancement act. R.S.A. 2000, c.E-12, as amended. Alberta Environment. Suncor Energy, Inc. Fort McMurray, Alberta. 105 pp.

Sinsabaugh, R.L., R.K. Antibus, A.E. Linkins, C.A. McClaugherty, L. Rayburn, D. Repert and T. Weiland. 1993. Wood decomposition: nitrogen and phosphorus dynamics in relation to extracellular enzyme activity. Ecology 74(5):1586-1593.

Sokal, R.R. and F.J. Rohlf. 1995. Biometry: the principles and practices of statistics in biological research. (3rd ed.). W.H. Freeman and Company. New York, New York, USA.

Stevens, V. 1997. The ecological role of coarse woody debris: an overview of the ecological importance of CWD in BC forests. Research Branch, British Columbia Ministry of Forests, Victoria, British Columbia. Working Paper 30/1997.

Stevenson, F.J. 1986. Cycles of soil: carbon, nitrogen, phosphorus, sulfur, micronutrients. John Wiley & Sons, Inc. USA.

Vance, E.D., P.C. Brookes and D.S. Jenkinson. 1987. An extraction method for measuring soil microbial biomass C. Soil Biology and Biochemistry 19(6):703-707.

Vogt, K.A., D.J. Vogt, H. Asbjornsen and R.A. Dahlgren. 1995. Roots, nutrients and their relationship to spatial patterns. Plant and Soil 168-169(1):113-123.

Wells J.M. and L. Boddy. 1990. Woody decay, and phosphorus and fungal biomass allocation, in mycelial cord systems. New Phytologist 116:285-295.

Whisenant, S. 2005. 50 first steps in erosion control. Forest Restoration in Landscapes. Springer, New York, New York. Pp. 350-351.

Winter Sydnor, M.E. and E.F. Redente. 2002. Ecosystem restoration: reclamation of high-elevation, acidic mine waste with organic amendments and topsoil. Journal of Environmental Quality 31:1528-1537.

Zimmerman J.K., W.M. Pulliam, D.J. Lodge, V. Quinones-Orfila, N. Fetcher, S. Guzmán-Grajales, J.A. Parrotta, C.E. Asbury, L.R. Walker and R.B. Waide. 1995. Nitrogen immobilization by decomposing woody debris and the recovery of tropical wet forest from hurricane damage. Oikos 72:314-322.

Zar, J.H. 1999. Biostatistical Analysis. (4th ed.). Prentice Hall. Upper Saddle River, New Jersey. 660 pp.

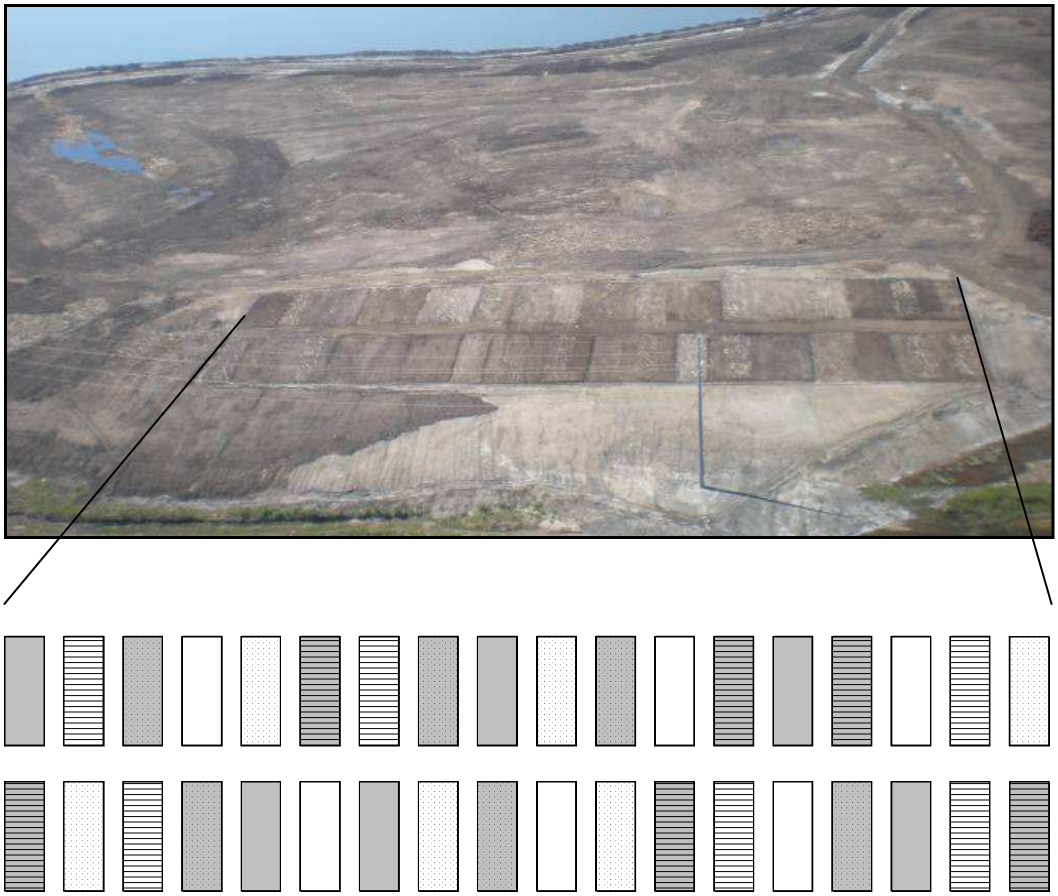

Figure 3.1 Experimental design of treatments on the reclaimed southeast dump at Suncor Energy Inc. Grey plots were covered with LFH, white plots were covered with peat. Plots without texture were control plots, plots with horizontal lines were covered with *Populus tremuloides* mixed wood woody debris and plots with dots were covered with *Picea mariana* woody debris.

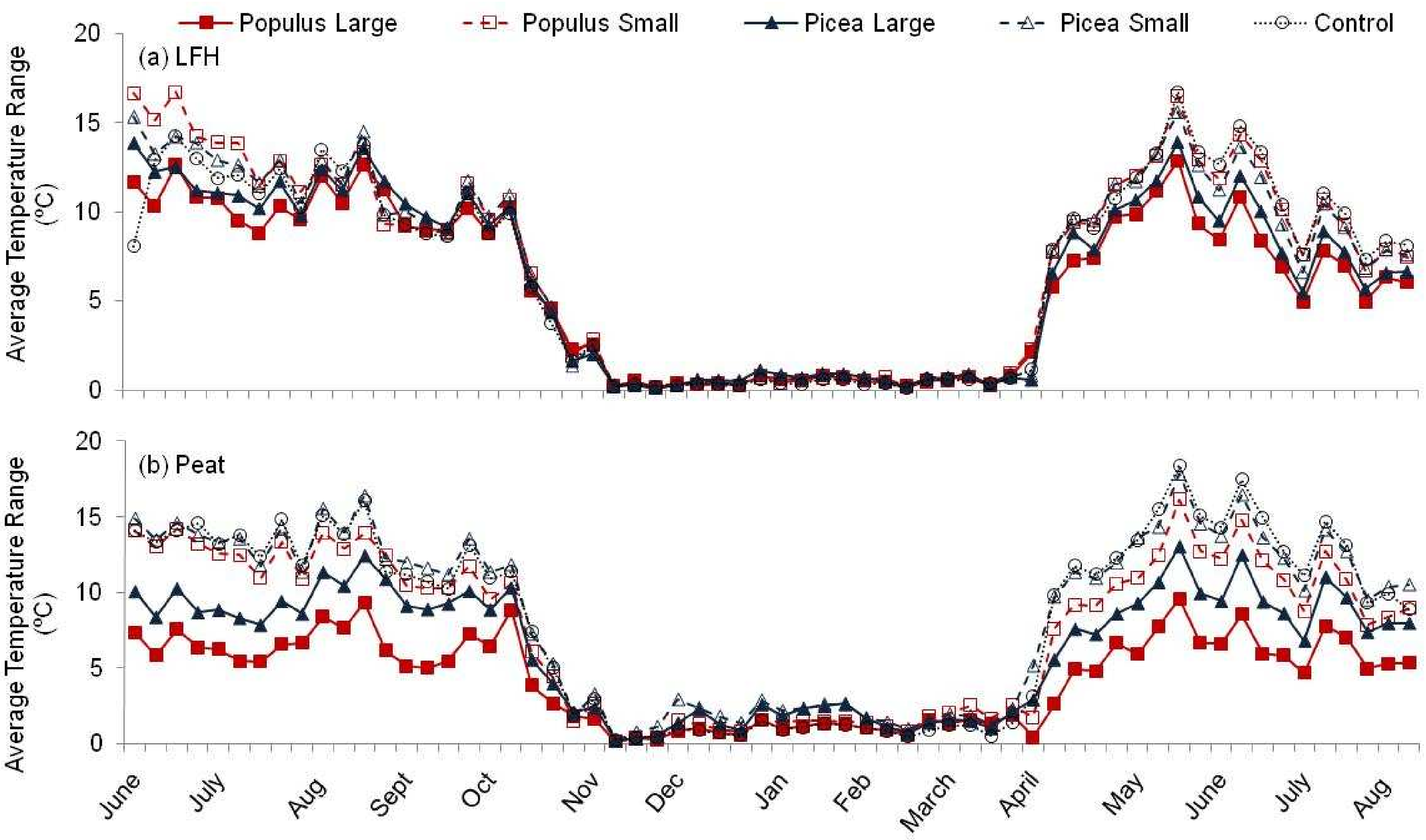

Figure 3.2 Mean weekly soil temperature range (℃) at 5 cm depth, starting June 1, 2008 and ending August 8, 2009.

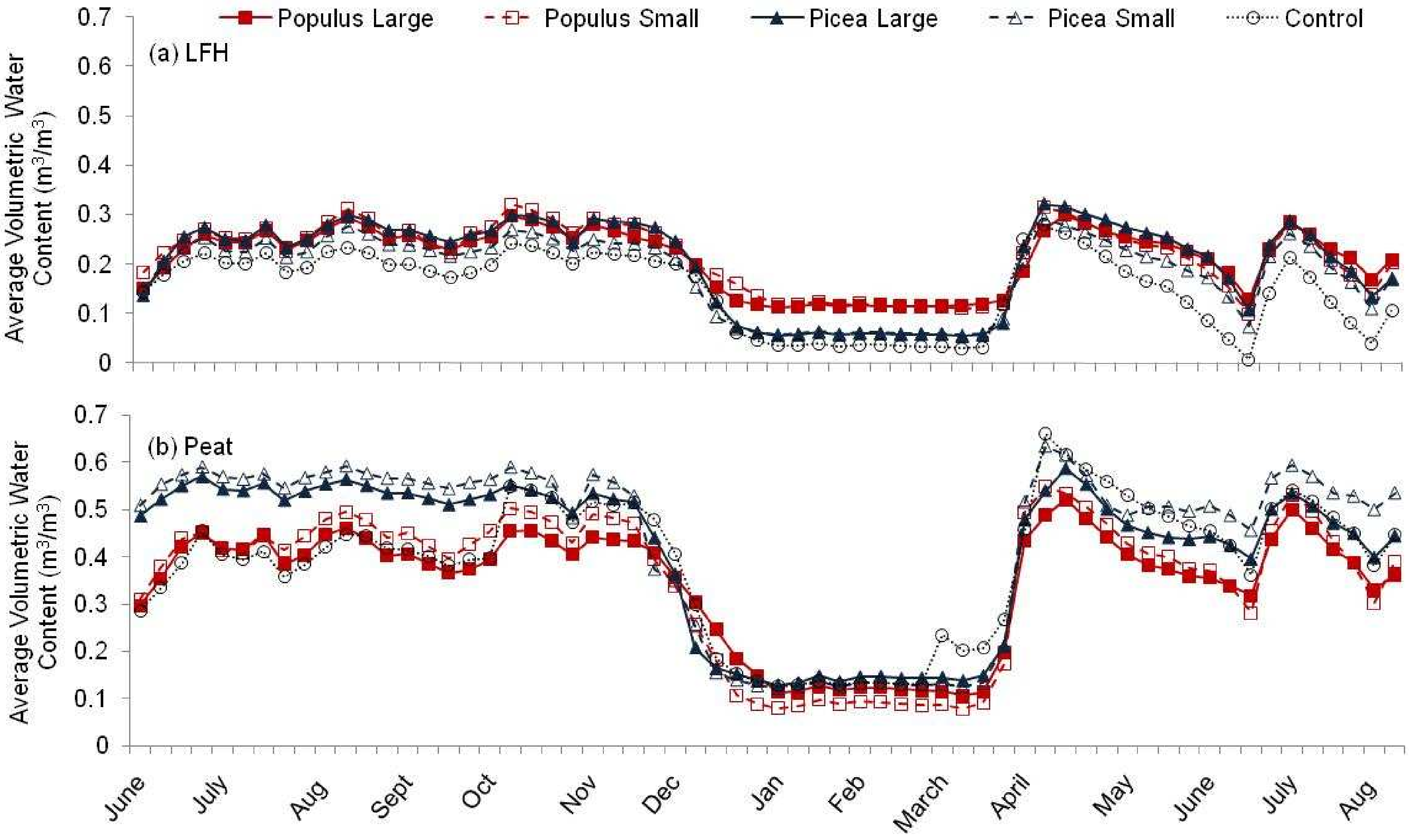

Figure 3.3 Mean weekly soil water content (m^3/m^3) at 5 cm depth, starting June 1, 2008 and ending August 8, 2009.

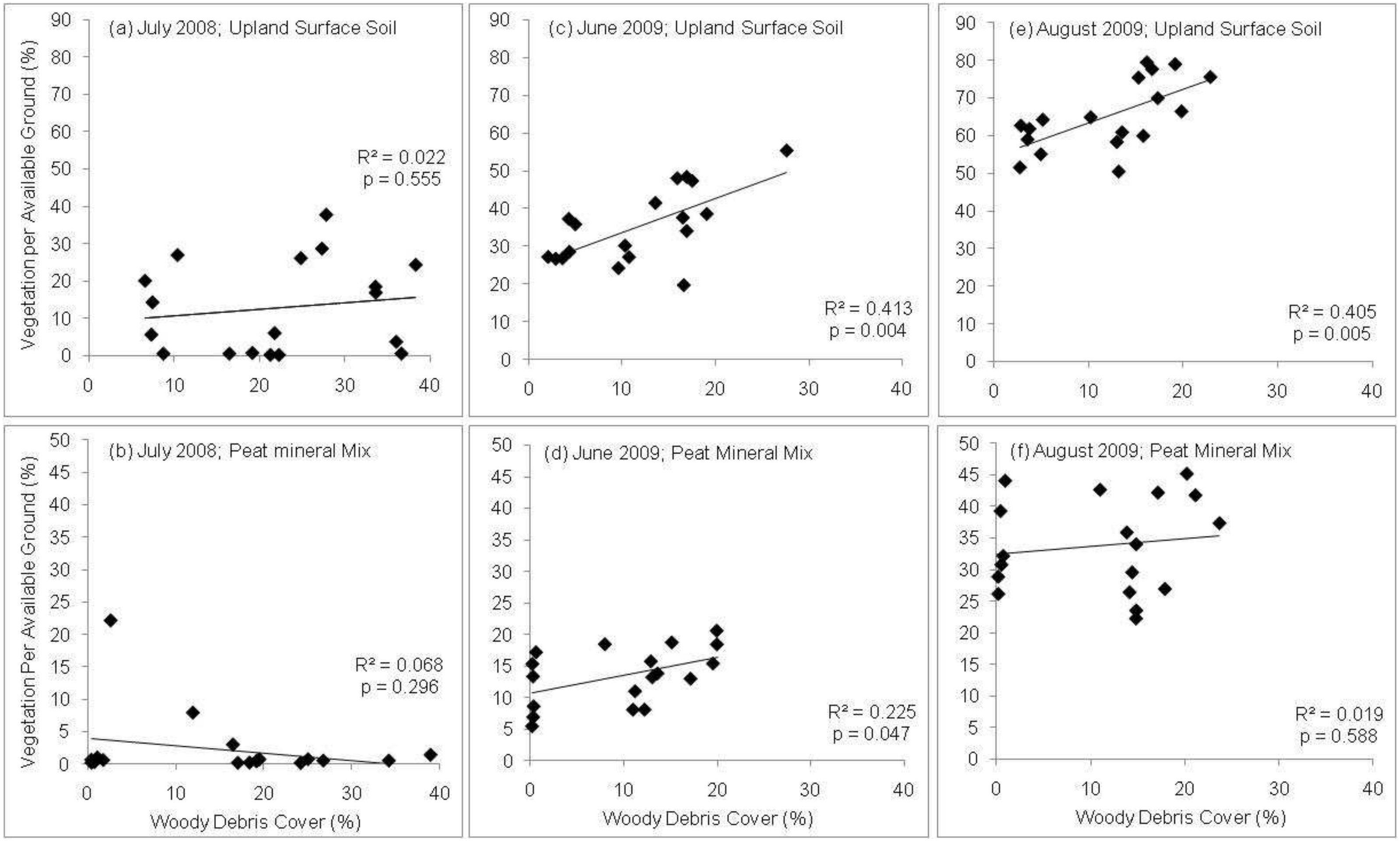

Figure 3.4 Regression analysis for the relationship between mean canopy covers of vegetation per available ground and woody debris (n = 18) during the first two growing seasons.

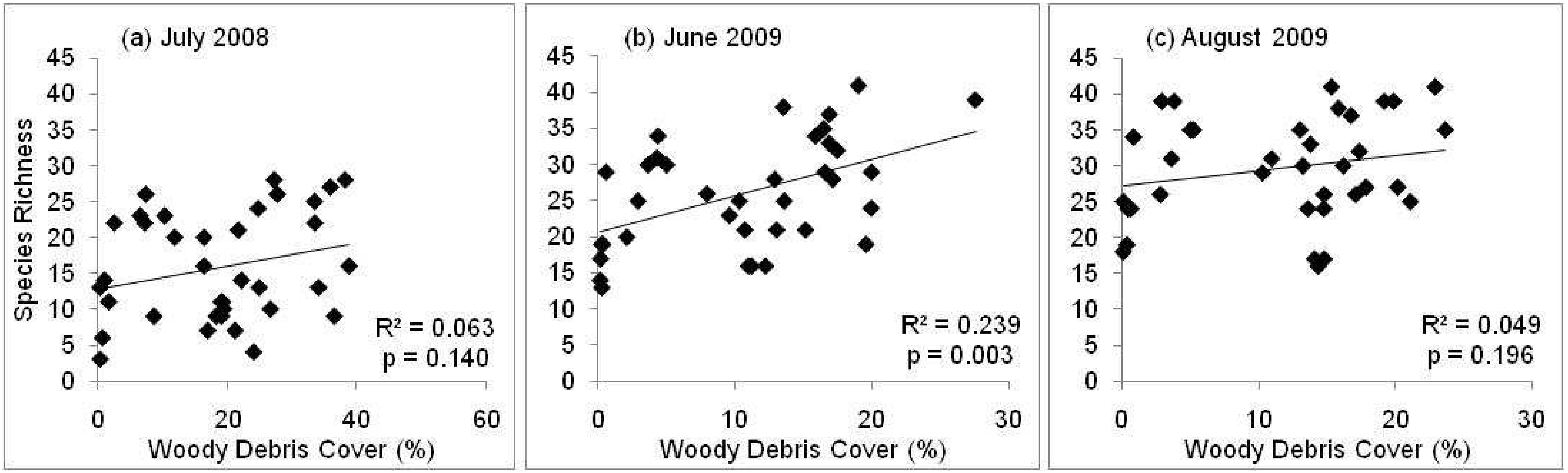

Figure 3.5 Regression analysis for the relationship between species richness and woody debris cover (n = 36) during the first two growing seasons.

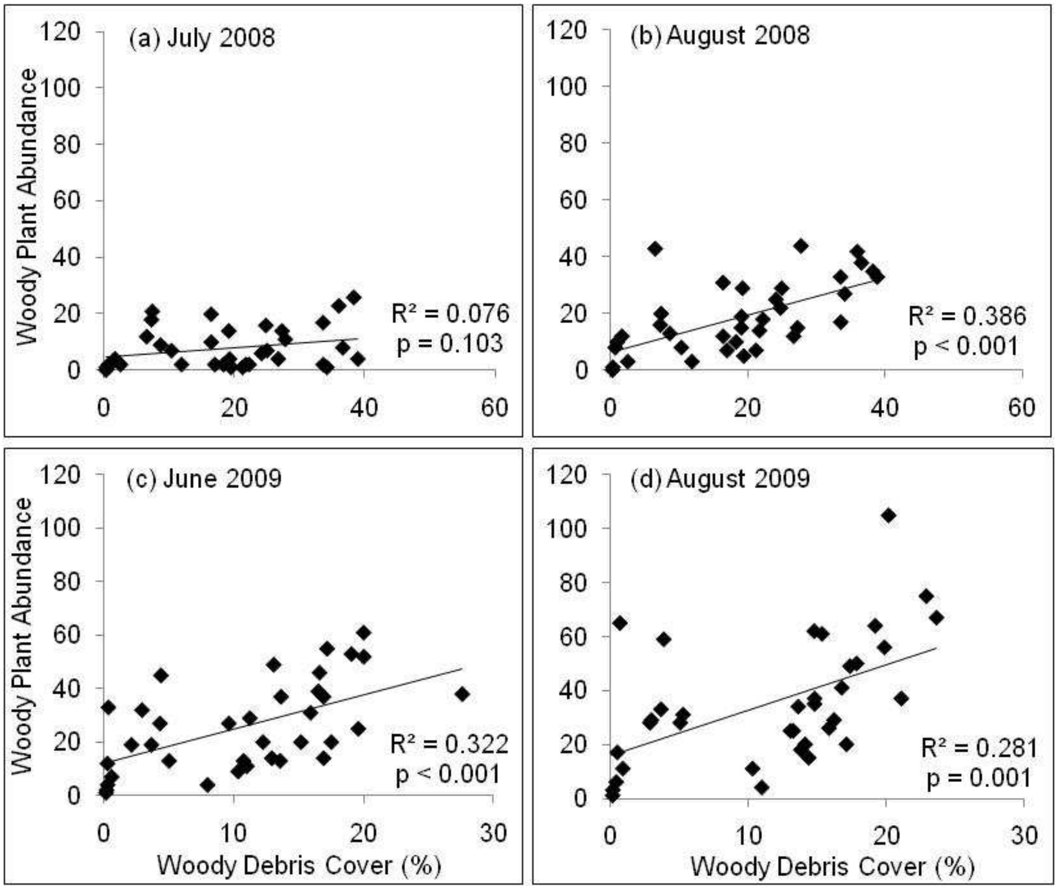

Figure 3.6 Regression analysis for the relationship between woody plant abundance per plot and woody debris cover (n = 36) during the first two growing seasons.

Table 3.1 Mean percent canopy cover of woody debris per size class (per 1 m^2), shortly after plot establishment (n = 6).

	LFH		Peat	
	Picea mariana	*Populus tremuloides*	*Picea mariana*	*Populus tremuloides*
Fine	10.3 (1.2)	2.2 (0.4)	6.2 (1.9)	1.4 (0.1)
Small	6.9 (0.9)	2.9 (0.3)	4.7 (0.8)	2.2 (0.4)
Medium	13.1 (1.0)	8.1 (0.6)	13.7 (1.7)	9.1 (1.1)
Large	0.5 (0.4)	2.7 (1.0)	2.5 (0.5)	5.4 (1.4)
Total	30.9 (1.5)	15.9 (1.5)	27.1 (3.3)	18.1 (1.7)

Numbers are means followed by standard errors in brackets.
Different letters denote significance between treatments at p < 0.050.

Table 3.2 Mean percent ground cover of woody debris per size class (per 1 m^2), shortly after plot establishment (n = 6).

	LFH		Peat	
	Picea mariana	*Populus tremuloides*	*Picea mariana*	*Populus tremuloides*
Fine	12.2 (1.8)	1.9 (0.2)	5.3 (1.7)	1.2 (0.1)
Small	4.3 (0.7)	2.4 (0.3)	3.1 (0.7)	1.7 (0.4)
Medium	5.7 (0.5)	4.6 (0.3)	8.6 (1.5)	5.5 (1.1)
Large	0.3 (0.2)	1.3 (0.5)	1.7 (0.3)	3.5 (1.2)
Total	22.4 (2.1)	10.2 (0.9)	18.7 (3.2)	11.8 (2.2)

Numbers are means followed by standard errors in brackets.
Different letters denote significance between treatments at $p < 0.050$.

Table 3.3 Presence (+) absence (-) of plant species per treatment identified during the first two growing seasons of a newly reclaimed site.

	Cover		Woody Debris		
Species	Peat	LFH	*Populus*	*Picea*	Control
Grasses					
Agropyron repens (L.) Beauv.	-	+	-	+	+
Agropyron trachycaulum (Link) Malte	+	+	+	+	+
Agrostis scabra Willd.	+	+	+	+	+
Beckmannia syzigachne (Steud.) Fern.	-	+	-	+	-
Bromus sp.	-	+	-	+	-
Bromus tectorum L.	-	+	+	-	-
Calamagrostis canadensis (Michx.) Beauv.	+	+	+	+	+
Cinna latifolia (Trev.) Griseb.	+	+	+	+	+
Dactylis glomerata L.	+	-	-	-	+
Deschampsia cespitosa (L.) Beauv.	+	+	+	+	+
Elymus innovatus Beal	+	+	+	+	+
Glyceria grandis S. Wats. ex A. Gray	+	+	+	+	+
Hordeum jubatum L.	+	+	+	+	+
Koeleria macrantha (Ledeb.) J.A. Schultes f.	+	+	-	+	+
Poa nervosa (Hook.) Vasey	+	+	+	+	+
Poa palustris L.	+	+	+	+	+
Poa pratensis L.	+	+	+	+	+
Sedge					
Carex sp.	+	+	+	+	+

Table 3.3 Presence (+) absence (-) of plant species per treatment identified during the first two growing seasons of a newly reclaimed site (continued).

	Cover		Woody Debris		
Species	Peat	LFH	*Populus*	*Picea*	Control
Forbs					
Achillea millefolium L.	+	+	+	+	+
Artemisia biennis Willd.	+	+	+	-	+
Aster ciliolatus Lindl.	+	+	+	+	+
Aster conspicuus Lindl.	+	-	+	-	-
Astragalus sp. L.	+	+	+	+	+
Cerastium vulgatum L.	-	+	+	-	+
Chenopodium album L.	+	+	+	+	+
Chenopodium capitatum (L.) Aschers.	+	+	+	+	+
Corydalis aurea Willd.	+	+	+	+	+
Corydalis sempervirens (L.) Pers.	+	+	+	+	+
Crepis tectorum L.	+	+	+	+	+
Dracocephalum parviflorum Nutt.	+	+	+	+	+
Epilobium angustifolium L.	+	+	+	+	+
Epilobium ciliatum Raf.	+	+	+	+	+
Epilobium glandulosum (Lehm.) Hoch & Raven	+	+	+	+	+
Fragaria vesca L.	+	+	+	+	+
Fragaria virginiana Duchesne	+	+	+	+	+
Galium boreale L.	+	-	+	-	-
Galium triflorum Michx.	-	+	-	+	-
Geranium bicknellii Britt.	+	+	+	+	+
Hieracium umbellatum L.	-	+	+	+	+
Kochia scoparia L. Schrad.	+	+	+	+	+
Lactuca serriola L.	+	+	+	+	+
Lathyrus ochroleucus Hook.	+	+	+	+	+
Lathyrus venosus Muhl.	+	+	+	+	+
Lepidium densiflorum Schrad.	+	+	+	+	-
Melilotus alba Desr.	-	+	-	+	-
Mertensia paniculata (Ait.) G. Don	+	+	+	+	+
Mitella nuda L.	-	+	-	+	-
Moehringia lateriflora (L.) Fenzl. In Moss	+	+	+	+	+
Petasites palmatus (Ait.) A. Gray	+	+	+	+	+
Petasites sagittatus (Pursh) A. Gray	+	-	+	+	-
Polygonum aviculare L.	-	+	+	+	-
Polygonum lapathifolium L.	+	-	-	+	+
Potentilla norvegica L.	+	+	+	+	+
Rubus pubescens Raf.	+	+	+	+	+
Salsola kali L.	+	+	+	+	+

Table 3.3 Presence (+) absence (-) of plant species per treatment identified during the first two growing seasons of a newly reclaimed site (continued).

	Cover Soil		Woody Debris		
Species	Peat	LFH	*Populus*	*Picea*	Control
Scenecio vulgaris L.	+	-	-	+	-
Solidago canadensis L.	+	+	+	+	+
Sonchus arvensis L.	+	+	+	+	+
Stellaria longifolia Muhl.	+	+	+	+	+
Taraxacum officinale Weber	+	+	+	+	+
Thalictrum venulosum Trel.	-	+	-	+	-
Trientalis borealis Raf.		+	+	+	+
Typha latifolia L.	+	-	+	-	-
Urtica dioica L.	+	+	+	+	+
Valeriana dioica L.	+	-	-	+	-
Vicia americana Muhl.	+	+	+	+	+
Viola adunca J.E. Smith	-	+	+	+	+
Pteridophyte					
Equisetum arvense L.	+	+	+	+	+
Woody					
Ledum groenlandicum Oeder	+	-	-	+	-
Picea mariana (Mill.) BSP.	+	+	-	+	-
Populus balsamifera	+	+	+	+	+
Populus tremuloides Michx.	+	+	+	+	+
Potentilla fruticosa L.	+	+	+	+	+
Ribes glandulosum Grauer	+	+	-	+	+
Ribes hudsonianum Richards.	+	+	+	+	+
Ribes lacustre (Pers.) Poir.	+	+	+	+	+
Ribes oxyacanthoides L.	+	+	+	+	-
Rosa acicularis Lindl.	+	+	+	+	+
Rubus idaeus L.	+	+	+	+	+
Salix sp. L.	+	+	+	+	+
Shepherdia canadensis (L.) Nutt.	+	-	-	-	+
Symphoricarpos occidentalis Hook.	+	-	-	+	-
Total	67	69	63	72	61

Table 3.4 Mean soil chemical and physical properties during the first two growing seasons for two cover types ($n = 30$).

		May 2008		August 2008		June 2009		August 2009	
		LFH	Peat	LFH	Peat	LFH	Peat	LFH	Peat
Avail. NO_3^{-} [1]	mg/kg	1.6 (0.4)^{b}	3.9 (0.4)^{a}	4.5 (0.8)	6.1 (0.9)	1.0 (0.2)	2.1 (0.8)	2.0 (0.0)	2.2 (0.2)
Avail. NH_4^{+}	mg/kg	-	-	1.0 (0.1)^{a}	< 0.3^{b}	0.9 (0.1)^{a}	0.4 (0.0)^{b}	-	-
Avail. P	mg/kg	14.1 (0.9)^{a}	5.1 (0.1)^{b}	21.3 (1.3)^{a}	7.1 (0.8)^{b}	24.9 (1.1)^{a}	19.0 (2.1)^{b}	32.4 (2.2)^{a}	16.0 (1.8)^{b}
Avail. K	mg/kg	124.0 (10.2)^{a}	71.0 (2.9)^{b}	-	-	-	-	137.0 (13.1)^{a}	97.0 (6.8)^{b}
Avail. SO_4	mg/kg	21.3 (2.5)^{b}	35.1 (5.0)^{a}	-	-	-	-	31.3 (8.8)^{b}	133.3 (14.0)^{a}
C:N		37.7 (1.0)^{b}	65.1 (5.4)^{a}	23.8 (1.6)	26.8 (0.3)	29.9 (0.5)^{a}	24.4 (0.4)^{b}	26.8 (0.4)^{a}	23.8 (0.6)^{b}
TOM	%	-	-	10.54 (1.20)^{b}	14.53 (1.08)^{a}	10.26 (1.23)^{b}	12.76 (0.60)^{a}	11.85 (1.47)	12.69 (0.99)
TOC	%	5.52 (0.75)^{b}	7.39 (0.48)^{a}	5.27 (0.60)^{b}	7.27 (0.54)^{a}	5.13 (0.62)^{b}	6.38 (0.30)^{a}	5.93 (0.74)	6.35 (0.49)
TN	%	0.15 (0.02)	0.14 (0.01)	0.39 (0.12)	0.27 (0.02)	0.18 (0.02)^{b}	0.27 (0.01)^{a}	0.22 (0.03)^{b}	0.27 (0.02)^{a}
Sand	%	55.2 (0.8)	54.3 (0.6)	-	-	-	-	53.3 (0.8)	51.4 (0.8)
Silt	%	32.2 (0.5)^{a}	29.6 (0.5)^{b}	-	-	-	-	34.4 (0.7)^{a}	29.8 (0.9)^{b}
Clay	%	12.6 (0.8)^{b}	16.1 (0.5)^{a}	-	-	-	-	12.3 (0.7)^{b}	18.7 (0.3)^{a}
pH		6.5 (0.1)^{b}	7.5 (0.0)^{a}	-	-	-	-	6.4 (0.1)^{b}	7.5 (0.0)^{a}
EC	dS/m	0.54 (0.04)	0.55 (0.03)	-	-	-	-	0.58 (0.05)^{b}	1.24 (0.08)^{a}
SAR		0.3 (0.0)^{b}	0.4 (0.0)^{a}	-	-	-	-	0.3 (0.0)^{b}	0.6 (0.1)^{a}

Avail. NO_3^{-} = available nitrate. Avail. NH_4^{+} = available ammonium. Avail. P = available phosphorus. Avail. K = available potassium. Avail. SO_4 = available sulphate. C:N = carbon nitrogen ratio. TOM = total organic matter. TOC = total organic carbon. TN = total nitrogen. EC = electrical conductivity. SAR = sodium adsorption ratio.

Numbers are means followed by standard errors in brackets

Different letters denote significance between treatments at $p < 0.100$.

1. May 2008: Available nitrate by method of modified kelowna extraction solution; detection limit of 1 mg/kg. August 2008, June 2009: Available nitrate by method of extraction with 2.0 M KCl; detection limit of 0.5 mg/kg. August 2009: Available nitrate by method of modified Kelowna extraction solution; detection limit of 2 mg/kg.

Table 3.5 Mean soil available nutrients through the first two growing seasons for woody debris treatments (n = 12).

	Populus tremuloides Large	*Populus tremuloides* Small	*Picea mariana* Large	*Picea mariana* Small	Control
Available Nitrate (mg/kg)					
May 2008^{1}	2.6 (0.6)	3.1 (0.9)	2.6 (0.5)	2.3 (0.4)	3.3 (1.0)
August 2008^{2}	3.7 (0.9)^{b}	5.1 (0.9)^{ab}	3.3 (0.8)^{b}	5.1 (1.2)^{ab}	9.3 (1.9)^{a}
June 2009^{2}	1.2 (0.3)^{a}	1.2 (0.3)^{a}	0.5 (0.0)^{b}	0.9 (0.2)^{ab}	3.8 (1.9)^{a}
August 2009^{3}	< 2.0	< 2.0	< 2.0	< 2.0	2.7 (0.6)
Available Phosphorus (mg/kg)					
May 2008	9.3 (1.6)	9.4 (1.9)	9.8 (1.8)	9.8 (1.7)	9.8 (1.7)
August 2008	15.1 (3.4)	13.8 (2.6)	13.5 (2.7)	15.7 (3.0)	13.0 (2.0)
June 2009	20.5 (3.2)	24.8 (2.4)	24.4 (3.6)	22.1 (2.0)	17.9 (2.3)
August 2009	26.2 (5.2)	21.8 (2.6)	27.7 (4.4)	24.8 (3.5)	20.8 (3.7)
Available Ammonium (mg/kg)					
August 2008	0.8 (0.2)	0.7 (0.2)	0.5 (0.1)	0.6 (0.1)	0.7 (0.3)
June 2009	0.6 (0.1)	0.7 (0.1)	0.5 (0.1)	0.6 (0.1)	0.8 (0.2)
Available Potassium (mg/kg)					
May 2008	93.3 (10.7)	105.0 (20.3)	95.0 (15.7)	88.3 (10.2)	105.8 (12.9)
August 2009	148.8 (27.5)	111.3 (13.1)	112.3 (15.2)	112.3 (13.1)	100.3 (13.0)
Available Sulphate (mg/kg)					
May 2008	25.1 (5.8)	26.6 (5.9)	28.3 (6.4)	22.7 (4.1)	38.3 (9.5)
August 2009	65.7 (19.7)	76.7 (21.3)	61.3 (15.3)	81.7 (22.3)	126.3 (34.3)

1. Available nitrate by method of modified Kelowna extraction solution; detection limit of 1 mg/kg.
2. Available nitrate by method of extraction with 2.0 M KCl; detection limit of 0.5 mg/kg.
3. Available nitrate by method of modified Kelowna extraction solution; detection limit of 2 mg/kg.

Numbers are means followed by standard errors in brackets.
Different letters denote significance between treatments at $p < 0.100$.

Table 3.6 Mean soil carbon nitrogen ratio, total organic carbon, total nitrogen, total organic matter, electrical conductivity and sodium adsorption ratio through the first two growing seasons between woody debris treatments (n = 12).

		Populus tremuloides Large	*Populus tremuloides* Small	*Picea mariana* Large	*Picea mariana* Small	Control
May 2008						
C:N		41.7 (3.1)	55.3 (6.3)	59.9 (11.9)	53.7 (8.2)	46.6 (2.7)
TOC	%	5.65 (0.87)	5.31 (1.10)	6.97 (1.22)	7.19 (1.19)	7.15 (0.70)
TN	%	0.13 (0.02)	0.11 (0.03)	0.15 (0.03)	0.16 (0.04)	0.16 (0.02)
EC	dS/m	0.57 (0.05)	0.53 (0.05)	0.57 (0.05)	0.49 (0.04)	0.58 (0.07)
SAR		0.3 (0.0)	0.3 (0.0)	0.3 (0.0)	0.3 (0.0)	0.3 (0.0)
August 2008						
C:N		27.5 (0.6)	27.3 (0.7)	22.6 (2.3)	21.9 (3.1)	27.1 (0.6)
TOC	%	5.64 (0.84)	7.59 (1.31)	5.65 (0.56)	6.79 (1.20)	5.68 (0.55)
TN	%	0.21 (0.03)	0.27 (0.05)	0.51 (0.28)	0.44 (0.11)	0.21 (0.02)
TOM	%	11.28 (1.68)	15.17 (2.62)	11.30 (1.12)	13.58 (2.41)	11.35 (1.10)
June 2009						
C:N		26.3 (0.8)	26.8 (0.6)	27.6 (1.3)	27.3 (1.1)	27.8 (1.4)
TOC	%	5.30 (0.75)	5.69 (0.80)	5.44 (0.69)	5.83 (1.04)	6.52 (0.66)
TN	%	0.21 (0.03)	0.22 (0.03)	0.21 (0.03)	0.22 (0.04)	0.25 (0.03)
TOM	%	10.58 (1.49)	11.39 (1.60)	10.89 (1.39)	11.66 (2.08)	13.04 (1.32)
August 2009						
C:N		25.2 (0.8)	25.1 (0.6)	26.2 (0.7)	24.7 (1.5)	25.4 (0.8)
TOC	%	5.96 (0.89)	5.62 (0.88)	6.80 (1.17)	5.71 (0.80)	6.61 (1.26)
TN	%	0.24 (0.04)	0.23 (0.04)	0.26 (0.05)	0.23 (0.03)	0.26 (0.05)
TOM	%	11.92 (1.77)	11.23 (1.76)	13.58 (2.33)	11.41 (1.59)	13.22 (2.51)
EC	dS/m	0.75 (0.09)	0.83 (0.11)	0.92 (0.13)	0.93 (0.14)	1.11 (0.22)
SAR		0.4 (0.1)	0.4 (0.0)	0.4 (0.1)	0.4 (0.0)	0.7 (0.1)

(C:N = carbon nitrogen ratio.TOC = total organic carbon. TN = total nitrogen. TOM = total organic matter. EC = electrical conductivity. SAR = sodium adsorption ratio.)

Numbers are means followed by standard errors in brackets.

Different letters denote significance between treatments at $p < 0.100$.

Table 3.7 Mean soil microbial biomass carbon (ppm) and root glucosamine (mg) / root (g) in the first growing season between cover and woody debris treatments.

	Cover		Woody Debris				
			Populus tremuloides		*Picea mariana*		Control
	LFH	Peat	Large	Small	Large	Small	
Microbial Biomass Carbon (ppm)	47.1 (3.8)^{a}	11.6 (1.8)^{b}	25.8 (5.1)	31.4 (7.4)	30.0 (6.6)	26.3 (7.2)	33.2 (8.8)
Glucosamine (mg)/ Root (g)	1.6 (0.10)^{a}	1.4 (0.06)^{b}	1.6 (0.10)		1.4 (0.09)		1.6 (0.13)

Numbers are means followed by standard errors in brackets.
Different letters denote significance between treatments at $p < 0.100$ for MBC and at $p < 0.050$ for Glucosamine.
Microbial biomass carbon (ppm) (Cover n = 30; Woody Debris n = 12).
Glucosamine (mg)/ root (g) (LFH n = 52; Peat n = 43; Aspen n = 30; Spruce n = 31; Control n = 34).

Table 3.8 Mean glucosamine (mg) / root (g) for root samples of three plant species in the first growing season.

	Achillea millefolium	*Geranium bicknellii*	*Rubus idaeus*
Glucosamine (mg)/ Root (g)	1.6 (0.10)^{a}	1.2 (0.07)^{b}	1.7 (0.13)^{a}

Numbers are means followed by standard errors in brackets.
Different letters denote significance between treatments as $p < 0.050$.
(*Achillea millefolium* n = 31; *Geranium bicknellii* n = 32; *Rubus idaeus* n = 32).

Table 3.9 Mean percent canopy cover of vegetation, bare ground and vegetation per available ground through the first two growing seasons between cover types (n = 18) and woody debris treatments (n = 12).

	Cover		Woody Debris		
	LFH	Peat	Aspen	Spruce	Control
Vegetation					
July 2008	9.8 (2.2)^{A}	2.0 (1.2)^{B}	4.7 (2.2)	5.9 (2.6)	7.1 (2.7)
June 2009	30.5 (1.6)^{A}	11.5 (0.9)^{B}	21.1 (3.0)	22.0 (3.7)	20.0 (3.0)
August 2009	56.7 (1.5)^{A}	29.7 (2.8)^{B}	42.1 (3.8)	42.7 (5.5)	44.8 (3.9)
Bare Ground					
July 2008	66.9 (3.3)^{B}	80.3 (2.9)^{A}	73.4 (3.0)^{b}	61.7 (3.4)^{c}	86.1 (3.3)^{a}
June 2009	54.4 (2.9)^{B}	76.6 (2.3)^{A}	63.7 (3.5)^{ab}	56.9 (4.8)^{b}	75.85 (3.8)^{a}
August 2009	16.0 (1.7)^{B}	50.2 (4.5)^{A}	32.3 (5.25)	28.2 (6.1)	40.0 (5.9)
Vegetation per Available Ground					
July 2008	12.8 (2.9)^{A}	2.3 (1.2)^{B}	6.2 (2.9)	8.7 (3.6)	7.7 (2.9)
June 2009	35.3 (2.3)^{A}	13.5 (1.1)^{B}	24.6 (3.6)	27.7 (4.8)	20.8 (3.2)
August 2009	65.1 (2.2)^{A}	33.9 (1.8)^{B}	49.5 (4.4)	52.6 (6.8)	46.3 (4.2)

Numbers are means followed by standard errors in brackets.
Different letters denote significance between treatments at $p < 0.100$.

Table 3.10 Mean percent canopy cover per species group through the first two growing seasons between cover types (n= 18).

	July 2008		June 2009		August 2009	
Plant Group	LFH	Peat	LFH	Peat	LFH	Peat
Forb	9.8 (2.4)^{a}	2.0 (1.2)^{b}	21.3 (1.4)^{a}	10.0 (0.8)^{b}	41.7 (2.7)^{a}	26.6 (2.9)^{b}
Pteridophyte	< 0.1^{b}	0.1 (0.0)^{a}	< 0.1^{b}	0.3 (0.1)^{a}	0.1 (0.1)^{b}	1.3 (0.5)^{a}
Grass	0.4 (0.1)^{a}	0.1 (0.1)^{b}	4.2 (0.7)^{a}	0.6 (0.2)^{b}	8.6 (2.2)^{a}	1.5 (0.8)^{b}
Sedge	0.1 (0.0)^{a}	< 0.1^{b}	4.4 (0.6)^{a}	0.2 (0.0)^{b}	6.2 (1.7)^{a}	0.6 (0.2)^{b}
Woody	0.2 (0.0)^{a}	< 0.1^{b}	1.0 (0.2)^{a}	0.5 (0.1)^{b}	3.9 (1.0)^{a}	1.8 (0.6)^{b}
Moss	0.25 (0.1)	0.5 (0.1)	0.1 (0.0)^{b}	0.3 (0.1)^{a}	16.5 (4.5)^{a}	5.7 (1.8)^{b}
Perennial	3.8 (0.9)^{a}	0.6 (0.2)^{b}	17.1 (1.5)^{a}	4.3 (0.6)^{b}	39.1 (5.05)^{a}	15.1 (3.0)^{b}
Annual / Biennial	6.8 (1.6)^{a}	1.7 (1.1)^{b}	13.8 (1.0)^{a}	7.4 (0.7)^{b}	21.5 (3.25)^{a}	16.7 (2.3)^{b}
Native	6.0 (1.4)^{a}	1.1 (0.6)^{b}	24.0 (1.7)^{a}	7.7 (1.1)^{b}	43.4 (4.1)^{a}	15.3 (2.5)^{b}
Introduced	4.4 (1.1)^{a}	1.1 (0.7)^{b}	2.2 (0.2)^{b}	3.5 (0.4)^{a}	10.4 (1.45)^{b}	15.2 (2.5)^{a}
Total with moss	10.9 (2.5)^{a}	2.8 (1.3)^{b}	31.1 (1.7)^{a}	12.0 (0.9)^{b}	77.2 (4.1)^{a}	37.6 (4.0)^{b}
Total without moss	10.6 (2.5)^{a}	2.2 (1.3)^{b}	30.9 (1.7)^{a}	11.7 (0.9)^{b}	60.6 (2.8)^{a}	31.8 (2.9)^{b}

Numbers are means followed by standard errors in brackets.
Different letters denote significance between treatments at $p < 0.100$.

Table 3.11 Mean biovolumes (L/m^2) during the second growing season between cover types (n = 18).

	June 2009		August 2009	
Plant Group	LFH	Peat	LFH	Peat
Forb	3.23 (0.18)^a	1.63 (0.17)^b	4.81 (0.46)^a	3.98 (0.61)^b
Pteridophyte	< 0.01^b	0.01 (0.01)^a	< 0.01^b	0.02 (0.02)^a
Grass	0.63 (0.09)^a	0.09 (0.03)^b	0.87 (0.23)^a	0.20 (0.10)^b
Sedge	0.74 (0.14)^a	0.03 (0.01)^b	0.59 (0.22)^a	0.05 (0.02)^b
Woody	0.17 (0.04)^a	0.09 (0.03)^b	0.44 (0.18)	0.24 (0.10)
Perennial	2.62 (0.16)^a	0.65 (0.13)^b	4.13 (0.54)^a	1.89 (0.53)^b
Annual/Biennial	2.14 (0.20)^a	1.20 (0.14)^b	2.58 (0.59)	2.60 (0.59)
Native	3.70 (0.22)^a	1.29 (0.21)^b	5.05 (0.52)^a	1.96 (0.50)^b
Introduced	0.26 (0.05)^b	0.49 (0.07)^a	0.99 (0.23)^b	2.41 (0.59)^a
Total	4.76 (0.25)^a	1.85 (0.18)^b	6.71 (0.61)^a	4.49 (0.62)^b

Numbers are means followed by standard errors in brackets.
Different letters denote significance between treatments at $p < 0.100$.

Table 3.12 Mean percent vegetation canopy cover by plant group during the first growing season between woody debris treatments (n = 12).

	Canopy Cover		
Plant Group	Aspen	Spruce	Control
Forb	4.7 (2.2)	5.7 (2.7)	7.4 (2.9)
Pteridophyte	< 0.1	0.1 (0.0)	< 0.1
Grass	0.1 (0.1)	0.2 (0.1)	0.4 (0.2)
Sedge	0.1 (0.0)	0.1 (0.0)	0.1 (0.0)
Woody	0.1 (0.05)	0.2 (0.1)	0.1 (0.0)
Moss	0.4 (0.1)^{ab}	0.7 (0.2)^a	0.1 (0.0)^b
Perennial	1.7 (0.9)	2.4 (1.0)	2.4 (0.9)
Annual/Biennial	3.3 (1.5)	4.0 (1.7)	5.6 (2.2)
Native	2.5 (1.2)	3.5 (1.6)	4.6 (1.7)
Introduced	2.4 (1.1)	2.6 (1.1)	3.3 (1.4)
Total with moss	5.4 (2.3)	6.9 (2.7)	8.15 (3.1)
Total without moss	5.0 (2.3)	6.3 (2.8)	8.0 (3.1)

Numbers are means followed by standard errors in brackets.
Different letters denote significance between treatments at $p < 0.100$.

Table 3.13 Mean percent vegetation canopy cover and biovolume (L/m^2) per species group at the beginning of second growing season between woody debris treatments (n = 12).

	Canopy Cover			Biovolume		
Plant Group	Aspen	Spruce	Control	Aspen	Spruce	Control
Forb	16.3 (2.1)	16.2 (2.5)	14.5 (2.0)	2.53 (0.30)	2.44 (0.36)	2.31 (0.30)
Pteridophyte	0.1 (0.1)	0.2 (0.1)	0.2 (0.1)	< 0.01	0.01 (0.01)	< 0.01
Grass	2.2 (0.8)	2.6 (0.8)	2.5 (0.9)	0.31 (0.10)	0.41 (0.12)	0.35 (0.12)
Sedge	2.1 (0.7)	2.3 (0.8)	2.6 (0.9)	0.36 (0.14)	0.36 (0.13)	0.44 (0.20)
Woody Plant	0.6 (0.1)	1.1 (0.3)	0.7 (0.2)	0.11 (0.05)	0.16 (0.04)	0.11 (0.04)
Moss	0.2 (0.1)^{b}	0.4 (0.1)^{a}	0.1 (0.0)^{b}	-	-	-
Perennial	10.0 (2.4)	12.1 (2.7)	10.1 (2.1)	1.53 (0.29)	1.82 (0.40)	1.56 (0.34)
Annual/Biennial	11.3 (1.4)	10.2 (1.2)	10.3 (1.6)	1.79 (0.30)	1.56 (0.19)	1.66 (0.28)
Native	16.4 (2.8)	15.8 (3.5)	15.5 (2.8)	2.59 (0.37)	2.46 (0.53)	2.45 (0.43)
Introduced	2.6 (0.3)^{b}	3.7 (0.5)^{a}	2.3 (0.3)^{b}	0.33 (0.07)	0.49 (0.10)	0.31 (0.07)
Total with moss	21.4 (3.0)	22.7 (3.7)	20.5 (3.0)	-	-	-
Total without moss	21.2 (3.1)	22.3 (3.8)	20.4 (3.0)	3.32 (0.46)	3.38 (0.56)	3.22 (0.52)

Numbers are means followed by standard errors in brackets.
Different letters denote significance between treatments at $p < 0.100$.

Table 3.14 Mean percent vegetation canopy cover and biovolume (L/m^2) per plant group at the end of second growing season between woody debris treatments (n = 12).

	Canopy Cover			Biovolume		
Plant Group	Aspen	Spruce	Control	Aspen	Spruce	Control
Forb	34.3 (2.7)	33.1 (3.8)	35.0 (2.4)	4.51 (0.34)	4.12 (0.50)	4.55 (0.36)
Pteridophyte	0.5 (0.3)	0.6 (0.2)	0.9 (0.4)	< 0.01	< 0.01	0.02 (0.01)
Grass	4.4 (1.3)	5.4 (1.5)	5.5 (1.8)	0.45 (0.13)	0.54 (0.15)	0.61 (0.20)
Sedge	3.3 (1.2)	3.3 (1.1)	3.6 (1.4)	0.37 (0.15)	0.28 (0.12)	0.32 (0.14)
Woody	2.2 (0.5)	3.6 (0.7)	2.7 (0.8)	0.28 (0.09)	0.43 (0.13)	0.31 (0.11)
Moss	12.6 (3.8)	9.3 (1.7)	11.6 (2.8)	-	-	-
Perennial	24.8 (4.1)	28.6 (5.3)	27.8 (4.5)	2.89 (0.48)	3.08 (0.59)	3.06 (0.45)
Annual/Biennial	19.9 (2.7)	17.5 (1.7)	19.9 (1.8)	2.73 (0.45)	2.29 (0.37)	2.75 (0.44)
Native	29.9 (4.4)	29.1 (5.6)	29.2 (4.7)	3.58 (0.54)	3.49 (0.70)	3.43 (0.52)
Introduced	11.2 (1.2)	12.6 (1.8)	14.7 (1.7)	1.61 (0.26)	1.48 (0.36)	2.02 (0.49)
Total with moss	57.6 (6.8)	55.4 (6.9)	59.4 (6.2)	-	-	-
Total without moss	44.8 (4.1)	46.1 (5.9)	47.8 (4.1)	5.62 (0.49)	5.36 (0.72)	5.82 (0.39)

Numbers are means followed by standard errors in brackets.
Different letters denote significance between treatments at $p < 0.100$.

Table 3.15 Mean species richness and native species richness during the first two growing seasons between cover treatments (n = 18) and woody debris treatments (n = 12).

	Cover		Woody Debris		
	LFH	Peat	Aspen	Spruce	Control
July 2008					
Total Species	20 (2)^{A}	12 (1)^{B}	15 (2)	17 (2)	16 (2)
Native Species	17 (1)^{A}	10 (1)^{B}	13 (2)	14 (2)	13 (2)
June 2009					
Total Species	31 (1)^{A}	21 (1)^{B}	26 (2)	29 (2)	23 (2)
Native Species	26 (1)^{A}	17 (1)^{B}	21 (2)	24 (2)	19 (2)
August 2009					
Total Species	34 (1)^{A}	25 (1)^{B}	29 (2)	31 (2)	29 (2)
Native Species	30 (1)^{A}	19 (1)^{B}	23 (2)	26 (2)	24 (2)

Numbers are means followed by standard errors in brackets.
Different letters denote significance between treatments at $p < 0.100$.

Table 3.16 Mean woody plant abundance per plot (15 m^{2}) during the first two growing seasons between cover treatments (n = 18) and woody debris treatments (n = 12).

	Cover		Woody Debris		
	LFH	Peat	Aspen	Spruce	Control
July 2008	12 (2)^{A}	3 (1)^{B}	6 (2)	9 (2)	8 (2)
August 2008	24 (3)^{A}	13 (2)^{B}	13 (2)^{b}	29 (3)^{a}	14 (4)^{b}
June 2009	28 (3)	24 (5)	20 (4)^{b}	40 (3)^{a}	18 (4)^{b}
August 2009	39 (7)	32 (12)	29 (7)^{b}	52 (4)^{a}	26 (6)^{b}

Numbers are means followed by standard errors in brackets.
Different letters denote significance between treatments at $p < 0.050$.

Table 3.17 Mean proportion of vegetation located near and away from woody debris within peat treatments during the second growing season for microsite analysis (n = 12).

	June 2009		August 2009	
	Near	Away	Near	Away
Cover				
Total	59 (3)^a	41 (3)^b	50 (2)	50 (2)
Vascular Plant	60 (3)^a	40 (3)^b	49 (3)	51 (3)
Moss	68 (7)^a	32 (7)^b	63 (4)^a	37 (4)^b
Native	53 (4)	47 (4)	51 (4)	49 (4)
Introduced	65 (4)^a	35 (4)^b	45 (2)^b	55 (2)^a
Biovolume				
Total	60 (4)^a	40 (4)^b	50 (4)	50 (4)
Native	53 (5)	47 (5)	52 (5)	48 (5)
Introduced	72 (5)^a	28 (5)^b	47 (4)	53 (4)
Woody Species				
Abundance	77 (4)^a	23 (4)^b	71 (5)^a	29 (5)^b
Cover	70 (6)^a	30 (6)^b	69 (6)^a	31 (6)^b
Biovolume	70 (9)^a	30 (9)^b	68 (7)^a	32 (7)^b
Salix Abundance	84 (5)^a	16 (5)^b	87 (4)^a	13 (4)^b

Numbers are means followed by standard errors in brackets.
Different letters denote significance between treatments at $p < 0.050$.

CHAPTER IV. SYNTHESIS AND FUTURE RESEARCH

1. RESEARCH SUMMARY

1.1 OVERVIEW

Two field research experiments were established to compare treatments with and without woody debris. One site was four years old and compared treatments with heavy cover of woody debris from a *Populus tremuloides* Michx. (trembling aspen) mixed wood forest to treatments without woody debris and a cover crop of *Hordeum vulgare* L. (common barley). Woody debris cover averaged 25 to 44% per plot. The other site was constructed in winter 2007 / 2008 and was studied through two growing seasons. This two year old site had treatments with a lighter cover of woody debris from a *Populus tremuloides* mixed wood forest, woody debris from a *Picea mariana* (Mill.) BSP (black spruce) forest, and no woody debris on upland surface soil and peat mineral mix covers. Upland surface soil is collected from a Luvisolic soil and is a mixture of LFH and Ae horizons (Singh 2007) (hereafter referred to as LFH). Peat mineral mix consists of 1 m of organic peat with 0.4 m of underlying mineral soil (Oil Sands Revegetation Reclamation Committee 1998, Singh 2007) (hereafter referred to as peat). Woody debris cover averaged between 10 and 40% per plot. All woody debris used was fresh collected during land clearing to prepare for oil sands mining.

Vegetation cover, composition and richness; survival and health of planted saplings; soil chemical and physical properties; microbial biomass carbon and mycorrhizal biomass measured by glucosamine; were evaluated on the four year old site. Vegetation cover, biovolume, composition and richness; woody plant abundance; soil temperature and water; soil chemical and physical properties; microbial biomass carbon and mycorrhizal biomass measured by glucosamine; were evaluated on the two year old site.

1.2 FOUR YEAR OLD SITE

Treatments with woody debris had sandier soils, lower available nitrate, higher available phosphorus and lower microbial biomass carbon. Wind blown soil particles were likely caught by woody debris and deposited on woody debris treatments. Microbial biomass carbon was higher on treatments without woody debris likely due to coarser soil and decomposition of barley. Lower available nitrate in woody debris soils could indicate immobilization in woody detritus (Harmon et al. 1986, Sinsabaugh et al. 1993, Zimmerman et al. 1995, Kayahara et al. 1996, Krankina et al. 1999, Laiho and Prescott 1999). Higher available phosphorus on woody debris treatments was likely from leachate from woody logs (Auerswald and Weigand 1996, Krankina et al. 1999, Kuehne et al. 2008). No difference in mycorrhizal biomass was found between treatments.

Treatments without woody debris had a greater vegetation canopy cover, but the majority of vegetation was introduced species, mainly *Sonchus arvensis* L. (perennial sow thistle). A much lower proportion of vegetation on woody debris treatments was introduced species and vegetation generally had greater evenness. Treatments with woody debris had greater species richness and greater proportions of planted saplings survived and were rated as healthy.

1.3 TWO YEAR OLD SITE

Treatments with woody debris had lower available nitrate, higher available phosphorus and lower temperature range. Treatments with woody debris on LFH had higher volumetric water content, but this trend was not apparent on peat likely due to its higher organic matter. There was no difference in microbial biomass carbon or mycorrhizal biomass between treatments with and without woody debris; however both were higher on treatments with LFH than peat.

Treatments without woody debris had more bare ground; treatments with woody debris had greater vegetation cover per available ground. A positive relationship was found between vegetation cover per available ground and woody debris cover in June 2009. Woody debris treatments had higher species richness and a positive relationship was found between species richness and woody debris cover in June 2009. Treatments with woody debris had greater woody plant abundance and a positive relationship between woody plant abundance and woody debris cover throughout most of this study. *Picea mariana* cones present in *Picea mariana* woody debris were able to produce viable saplings.

By June 2009, most plants on peat treatments grew in close proximity to woody debris. However plants spread from woody debris microsites by August 2009, likely facilitated by microsites created by other plants. A greater proportion of woody plant abundance and cover was found in close proximity to woody debris in June and August of the second growing season. Microsites created by woody debris likely provided favourable growing environments for woody species.

2. APPLICATIONS FOR RECLAMATION

This research has shown the importance of woody debris in survival of planted saplings and accumulation of naturally regenerated woody plants. *Picea mariana* woody debris was a propagule source for *Picea mariana* saplings. Reclaiming oil sands to upland forests can be complicated. Adding woody debris appears to facilitate this transformation by providing microsites with more favourable growing conditions. A positive relationship was found between woody plant abundance and woody debris cover. However, lower and upper limits of woody debris application have not been determined and research is required. Species richness and vegetation cover per available ground were positively related to woody debris cover during the post winter assessment. Winters in northern Alberta can present harsh environments that can inhibit seedling survival. Woody debris microsites can protect seedlings during this time and provide vegetation with a head start for the coming growing season.

Nitrogen immobilization in decomposing woody debris was detected. Immobilization can make nutrients unavailable for vegetation and suppress growth (Zimmerman et al. 1995). Although woody debris leachate is contributing phosphorus to the soil, phosphorus will likely be immobilized during later stages of decay (Wells and Boddy 1990, Sinsabaugh et al. 1993, Kayahara et al. 1996, Laiho and Prescott 1999). Reclamation sites at Suncor Energy, Inc. are fertilized during the first five years. Fertilization likely negates any detrimental effects immobilization might cause during early stages of plant development. Research is necessary to determine if five years of fertilization are enough. Immobilization provides beneficial results by maintaining nutrients on site and preventing nutrient leaching. Nutrients contained in woody biomass will be released and available for plant consumption once woody debris has decomposed. Woody debris might help stabilize nutrients in areas of disturbance by preventing them from leaching or eroding off site.

Currently, islands of woody debris have been applied to random locations on the south east dump. These islands have heavy cover and pieces of woody debris are piled on top of each other. Logs not in contact with the soil surface will likely take longer to decompose. Value of logs might be maximized if they are better spread, covering a larger area of land or requiring less wood to cover the same area. Research on alternative application methods would be worthwhile to reduce application time and increase positive outcomes.

3. FUTURE RESEARCH

This research clearly defined the value of woody debris in reclaiming degraded land after oil sands mining. Future research is necessary to determine optimal application methods and continued research will map long term trends. The following research is suggested.

- Continued research on sites studied in this thesis. This research provides baseline numbers for microbial biomass carbon and mycorrhizal biomass for future comparison. Trends in nutrient cycling can be determined. Effects of changes in microbial populations and nutrients dynamics on vegetation growth can be assessed. The experimental design of this project provides a great opportunity to determine long term changes and trends.
- Appropriate woody debris cover. This study generally shows heavier covers of woody debris are associated with greater woody plant abundance, species richness and vegetation cover per available ground. However, an upper limit of woody debris cover has not been identified. Plants need space to grow and too heavy a cover could yield negative outcomes, such as severe nutrient limitation.
- Appropriate application methods. In this research woody debris was applied with a backhoe with grapple device and a person manually moving logs to maximize contact between soil and logs. More effective, less time consuming methods could be developed.

- Incorporating logs into the soil. Woody debris in this study was placed on top of the soil. However, beneficial results might occur if logs were incorporated into the soil, thus creating maximum contact between wood and soil. Alternatively, incorporated logs might provide less protection against wind.
- Fertilizer application. Research can determine what would happen if plots were not fertilized, what happens when fertilization stops after five years and if sites should be fertilized for longer periods.
- Appropriate locations for woody debris amendments. *Picea mariana* woody debris might be a good amendment to use on low lying areas, since *Picea mariana* is generally not an upland species.
- Other microsites. Research can determine if other forms of microsites, such as hummocks and rocks, will produce similar positive results. Heterogeneous research plots with soil hummocks can be compared to homogeneous plots where soil is spread flat.
- Amendments of more decayed woody debris. Research can determine if adding woody debris in later decay classes has added benefits. Further decayed wood can provide substrate for vegetation growth and may increase species richness, particularly of moss species.
- Rate of decay. The rate of decay can be determined for logs in this study. Decay rates are expected to be slow. Logs are not under a forest canopy and lack a suitable moisture status for high decomposition rates. Microbial and invertebrate colonization may be slow. Such rates would help determine future trends in nutrient cycling and microbial colonization.
- Phospholipid fatty acid microbial analysis. Microbial composition of soil and woody debris would be interesting to determine and assess over time.
- Moss, fungi and lichen. Species of moss, fungi and lichen that develop over time could be identified and assessed. Currently only a few species of moss were found growing on site, but that is expected to increase with time.
- Invertebrates. Species of invertebrates could be identified and assessed.
- Soil from a shallower depth. Differences in microbial biomass and soil chemical properties might be more apparent at shallower depths under woody debris.
- Woody debris transport. A Caterpillar 740 articulated dump truck was used to transport woody debris. One truck load of woody debris can cover 10 x 40

m² with 15 to 30% cover. Truck loads of *Picea mariana* woody debris cover a larger area due to more small pieces of wood. Thus cover with *Populus tremuloides* mixed wood woody debris would be closer to 15% and cover with *Picea mariana* would be closer to 25 or 30%. A cost benefit analysis might help determine appropriate woody debris use.

4. LITERATURE CITED

Auerswald, K. and S. Weigand. 1996. Ecological impact of dead-wood hedges; release of dissolved phosphorus and organic matter into runoff. Ecological Engineering 7:183-189.

Harmon, M.E., J.F. Franklin, F.J. Swanson, P. Sollins, S.V. Gregory, J.D. Lattin, N.H. Anderson, S.P. Cline, N.G. Aumen, J.R. Sedell, G.W. LienKaemper, K. Cromack Jr. and K.W. Cummins. 1986. Ecology of coarse woody debris in temperate ecosystems. Advances in Ecological Research 15:133-302.

Kayahara, G.J., K. Klinka and L.M. Lavkulich. 1996. Effects of decaying wood on eluviation, podzolization, acidification, and nutrition in soils with different moisture regimes. Environmental Monitoring and Assessment 39:485-492.

Krankina, O.N., M.E. Harmon and A.V. Griazkin. 1999. Nutrient stores and dynamics of woody detritus in a boreal forest: modeling potential implications at the stand level. Canadian Journal of Forest Research 29:20-32.

Kuehne, C., C. Donath, S.I. Muller-Using and N. Bartsch. 2008. Nutrient fluxes via leaching from coarse woody debris in a *Fagus sylvatica* forest in the Solling Mountains, Germany. Canadian Journal of Forest Research 38:2405-2413.

Laiho, R. and C.E. Prescott. 1999. The contribution of coarse woody debris to carbon, nitrogen, and phosphorus cycles in three Rocky Mountain coniferous forests. Canadian Journal of Forest Research 29:1592-1603.

Oil Sands Revegetation Reclamation Committee. 1998. Guidelines to reclamation to forest vegetation in the Athabasca Oil Sands Region. Fort McMurray, Alberta. 212 pp.

Singh, K. 2007. Approval: province of Alberta, environmental protection and enhancement act. R.S.A. 2000, c.E-12, as amended. Alberta Environment. Suncor Energy, Inc. Fort McMurray, Alberta. 105 pp.

Sinsabaugh, R.L., R.K. Antibus, A.E. Linkins, C.A. McClaugherty, L. Rayburn, D. Repert and T. Weiland. 1993. Wood decomposition: nitrogen and phosphorus dynamics in relation to extracellular enzyme activity. Ecology 74(5):1586-1593.

Wells J.M. and L. Boddy. 1990. Woody decay, and phosphorus and fungal biomass allocation, in mycelial cord systems. New Phytologist 116:285-295.

Zimmerman J.K., W.M. Pulliam, D.J. Lodge, V. Quinones-Orfila, N. Fetcher, S. Guzmán-Grajales, J.A. Parrotta, C.E. Asbury, L.R. Walker and R.B. Waide. 1995. Nitrogen immobilization by decomposing woody debris and the recovery of tropical wet forest from hurricane damage. Oikos 72:314-322.

APPENDIX A. P-VALUES FOR ANALYSES FROM CHAPTERS II AND III

A.1 P-VALUES FOR CHAPTER II

Table A.1.1 P-values for percent canopy cover.

	p-value
Species Richness	0.269
Vegetation	0.005
Bare Ground	0.843
Litter	0.051
Woody Debris	0.005
Rock	0.903
Moss	0.700
Available Ground	0.005
Vegetation / Available Ground	0.224

Table A.1.2 P-values for percent canopy cover of plant groups.

Groups	p-value
Total	0.007
Grass	0.400
Sedge	0.322
Forb	0.009
Pteridophyte	0.858
Woody	0.400
Native	0.545
Introduced	0.026
Perennial	0.002
Annual/Biennial	0.364

Table A.1.3 P-values for cover of most common species.

Species	p-value
Achillea millefolium	0.177
Aster ciliolatus	0.564
Calamagrostis canadensis	0.388
Epilobium angustifolium	0.623
Equisetum arvense	0.858
Erigeron canadensis	0.369
Fragaria virginiana	0.422
Hieracium umbellatum	0.616
Hordeum jubatum	1.000
Rubus idaeus	0.787
Salix sp.	0.127
Urtica dioica	0.369
Sonchus arvensis	0.019

Table A.1.4 P-values for proportion sapling health.

	Treatment	Species	Interaction
Healthy	0.005	0.223	0.372
Marginal	0.195	0.375	0.263
Unhealthy	0.981	0.981	0.201
Dead	0.004	0.516	0.914
Present	0.003	0.542	0.866
Missing	0.003	0.542	0.866

Table A.1.5 P-values for Tukey post hoc multiple comparison test for proportion sapling health.

	WD Healthy vs. NW Healthy	WD Dead vs. NW Dead	WD Present vs. NW Present	WD Missing vs. NW Missing
Picea glauca	0.010	0.026	0.024	0.024
Populus tremuloides	0.077	0.021	0.017	0.017

WD = woody debris; NW = no woody debris.

Table A.1.6 P-values for sapling height.

	p-value
Picea glauca	0.039
Populus tremuloides	0.629

Table A.1.7 P-values for soil chemical and physical properties .

	p-value
Total Carbon	0.008
Total Organic Carbon	0.008
Total Nitrogen	0.040
C:N	0.981
Available Nitrate	0.007
Available Phosphorus	0.089
Available Potassium	0.100
Available Sulphate	0.979
Sodium Adsorption Ratio	1.000
Electrical Conductivity	0.359
pH	0.561
Sand	0.033
Silt	0.811
Clay	0.014

Table A.1.8 P-values for 2 way ANOVA on glucosamine content for roots and microbial biomass carbon for rhizosphere of six species.

Microbial Analyses	Treatment	Species	Interaction
Microbial Biomass Carbon (ppm)	<0.001	<0.001	0.002
Glucosamine per Oven Dried Root (mg/g)	0.711	<0.001	0.424

Table A.1.9 P-values for Tukey post hoc multiple comparison test for treatment differences in microbial biomass carbon analysis.

Species	Woody Debris vs No Woody Debris
Achillea millefolium	0.186
Agrostis scabra	0.266
Calamagrostis canadensis	0.003
Equisetum arvense	< 0.001
Fragaria virginiana	< 0.001

Table A.1.10 P-values for Tukey post hoc multiple comparison test for species differences in microbial biomass carbon analysis.

	Achillea millefolium	*Agrostis scabra*	*Calamagrostis canadensis*	*Equisetum arvense*	*Fragaria virginiana*
Achillea millefolium		< 0.001	0.303	< 0.001	0.031
Agrostis scabra	< 0.001		< 0.001	0.810	0.006
Calamagrostis canadensis	0.303	< 0.001		0.280	0.991
Equisetum arvense	< 0.001	0.810	0.280		0.062
Fragaria virginiana	0.031	0.006	0.991	0.062	

Table A.1.11 P-values for Tukey post hoc multiple comparison test for species differences in glucosamine analysis.

	Achillea millefolium	*Agrostis scabra*	*Calamagrostis canadensis*	*Epilobium angustifolium*	*Equisetum arvense*	*Fragaria virginiana*
Achillea millefolium		0.999	< 0.001	0.458	0.997	0.976
Agrostis scabra	0.999		< 0.001	0.702	1.000	0.863
Calamagrostis canadensis	< 0.001	< 0.001		< 0.001	< 0.001	0.002
Epilobium angustifolium	0.458	0.702	< 0.001		0.737	0.142
Equisetum arvense	0.997	1.000	< 0.001	0.737		0.836
Fragaria virginiana	0.976	0.863	0.002	0.142	0.836	

A.2 P-VALUES FOR CHAPTER III

Table A.2.1 P-values for Scheirer Ray Hare test on soil properties.

	June 2008			August 2008			June 2009			August 2009		
	Soil	WD	Interaction	Soil	WD	Interaction	Soil	WD	Interaction	Soil	WD	Interaction
Available Nitrate	< 0.001	0.997	0.583	0.178	0.056	0.235	0.738	0.053	0.249	0.981	0.087	1.000
Available Ammonium	-	-	-	< 0.001	0.748	0.748	< 0.001	0.750	0.875	-	-	-
Available Phosphorus	< 0.001	0.999	0.985	< 0.001	0.979	0.754	< 0.001	0.578	0.191	< 0.001	0.865	0.723
Available Potassium	< 0.001	0.762	0.631	-	-	-	-	-	-	0.006	0.496	0.331
Available Sulphate	0.008	0.385	0.284	-	-	-	-	-	-	< 0.001	0.837	0.258
C:N	< 0.001	0.550	0.589	0.905	0.215	0.101	< 0.001	0.893	0.643	< 0.001	0.878	0.651
Total Organic Matter	-	-	-	0.001	0.903	0.372	0.003	0.667	0.930	0.122	0.905	0.888
Total Organic Carbon	< 0.001	0.262	0.924	0.001	0.898	0.368	0.003	0.672	0.923	0.124	0.903	0.884
Total Nitrogen	0.905	0.236	0.427	0.131	0.120	0.220	< 0.001	0.871	0.956	0.024	0.996	0.962
Sand	0.174	0.301	0.720	-	-	-	-	-	-	0.141	0.966	0.582
Silt	< 0.001	0.522	0.935	-	-	-	-	-	-	< 0.001	0.988	0.392
Clay	< 0.001	0.925	0.969	-	-	-	-	-	-	< 0.001	0.999	0.905
pH	< 0.001	0.819	0.943	-	-	-	-	-	-	< 0.001	0.907	0.909
Electrical Conductivity	0.917	0.710	0.049	-	-	-	-	-	-	< 0.001	0.907	0.223
Sodium Adsorption Ratio	< 0.001	0.882	0.991	-	-	-	-	-	-	< 0.001	0.590	0.739
Microbial Biomass Carbon	-	-	-	< 0.001	0.970	0.964	-	-	-	-	-	-

Table A.2.2 P-values for Mann-Whitney post hoc test for differences in amendment treatments for available nitrate.

	Aspen L x Aspen S	Aspen L x Spruce L	Aspen L x Spruce S	Aspen L x Control	Aspen S x Spruce L	Aspen S x Spruce S	Aspen S x Control	Spruce L x Spruce S	Spruce L x Control	Spruce S x Control
August 2008	0.244	0.620	0.451	0.024	0.108	0.749	0.131	0.269	0.011	0.104
June 2009	0.825	0.021	0.438	0.401	0.044	0.594	0.316	0.104	0.003	0.130
August 2009	1.000	1.000	1.000	0.149	1.000	1.000	0.149	1.000	0.149	0.149

L = large; S = small.

Table A.2.3 P-values for Mann-Whitney post hoc test of significant interactions.

	May 2008 Electrical Conductivity
LFH	
Aspen L x Aspen S	0.522
Aspen L x Spruce L	0.575
Aspen L x Spruce S	0.630
Aspen L x Control	0.335
Aspen S x Spruce L	0.109
Aspen S x Spruce S	0.688
Aspen S x Control	0.936
Spruce L x Spruce S	0.199
Spruce L x Control	0.065
Spruce S x Control	0.748
Peat	
Aspen L x Aspen S	0.748
Aspen L x Spruce L	0.125
Aspen L x Spruce S	0.109
Aspen L x Control	0.261
Aspen S x Spruce L	0.106
Aspen S x Spruce S	0.055
Aspen S x Control	0.574
Spruce L x Spruce S	0.810
Spruce L x Control	0.024
Spruce S x Control	0.037
Aspen L	
LFH x Peat	0.631
Aspen S	
LFH x Peat	0.150
Spruce L	
LFH x Peat	0.029
Spruce S	
LFH x Peat	0.574
Control	
LFH x Peat	0.296

L = large; S = small.

Table A.2.4 P-values for 3 way ANOVA on glucosamine content.

	Soil	Woody Debris	Plant	Soil x Woody Debris	Soil x Plant	Woody Debris x Plant	Soil x Woody Debris x Plant
Glucosamine (µg)/ root (g)	0.028	0.230	0.005	0.935	0.383	0.089	0.757

Table A.2.5 P-values for Mann-Whitney post hoc test for vegetation differences.

	Rubus idaeus x *Geranium bicknellii*	*Rubus idaeus* x *Achillea millefolium*	*Achillea millefolium* x *Geranium bicknellii*
Glucosamine (µg)/ root (g)	0.002	0.880	0.003

Table A.2.6 P-values for Scheirer Ray Hare test on canopy cover of vegetation, bare ground and vegetation per available ground

	Soil	Woody Debris	Interaction
Vegetation			
July 2008	0.008	0.648	0.521
June 2009	< 0.001	0.909	0.829
August 2009	< 0.001	0.911	0.355
Bare Ground			
July 2008	0.016	< 0.001	0.924
June 2009	< 0.001	0.025	0.937
August 2009	< 0.001	0.251	0.782
Vegetation per Available Ground			
July 2008	0.003	0.934	0.372
June 2009	< 0.001	0.577	0.795
August 2009	< 0.001	0.739	0.317

Table A.2.7 P-values for Mann-Whitney test to determine differences between woody debris treatments.

Bare Ground	Aspen x Spruce	Aspen x Control	Spruce x Control
July 2008	0.024	0.018	< 0.001
June 2009	0.356	0.057	0.011

Table A.2.8 P-values for Scheirer Ray Hare test analyzing vegetation cover per plant group.

	July 2008			June 2009			August 2009		
	Soil	WD	Interaction	Soil	WD	Interaction	Soil	WD	Interaction
Forb	0.011	0.624	0.376	< 0.001	0.818	0.973	< 0.001	0.911	0.416
Pteridophyte	< 0.001	0.413	0.980	< 0.001	0.347	0.888	< 0.001	0.608	0.955
Grass	0.004	0.648	0.702	< 0.001	0.866	0.866	< 0.001	0.822	0.705
Sedge	< 0.001	0.884	0.947	< 0.001	0.853	0.907	< 0.001	0.794	0.863
Woody	< 0.001	0.787	0.823	0.058	0.122	0.273	0.003	0.101	0.317
Moss	0.103	0.015	0.720	0.058	0.013	0.974	< 0.001	0.928	0.598
Perennial	0.001	0.476	0.761	< 0.001	0.828	0.777	< 0.001	0.890	0.375
Annual/Biennial	0.013	0.723	0.573	< 0.001	0.803	0.889	0.076	0.497	0.734
Native	0.006	0.624	0.593	< 0.001	0.921	0.797	< 0.001	0.954	0.603
Introduced	0.033	0.783	0.399	0.019	0.093	0.583	0.014	0.205	0.620
Total with Moss	0.079	0.893	0.406	< 0.001	0.896	0.853	< 0.001	0.823	0.872
Total without Moss	0.004	0.551	0.557	< 0.001	0.921	0.853	< 0.001	0.928	0.349

Table A.2.9 P-values for post hoc Mann-Whitney test to determine differences between woody debris treatments.

	Aspen x Spruce	Aspen x Control	Spruce x Control
June 2008			
Moss Cover	0.157	0.112	0.005
July 2009			
Moss Cover	0.017	0.378	0.010
Introduced Cover	0.100	0.356	0.057

Table A.2.10 P-values for Scheirer Ray Hare test for plant group biovolume.

	June 2009			August 2009		
	Soil	WD	Interaction	Soil	WD	Interaction
Forb	< 0.001	0.823	0.981	0.066	0.848	0.160
Pteridophyte	< 0.001	0.413	0.797	< 0.001	0.567	0.944
Grass	< 0.001	0.841	0.871	< 0.001	0.830	0.485
Sedge	< 0.001	0.979	0.862	< 0.001	0.633	0.856
Woody	0.085	0.155	0.479	0.189	0.228	0.363
Perennial	< 0.001	0.714	0.598	< 0.001	0.979	0.230
Annual/Biennial	0.004	0.905	0.861	0.950	0.643	0.256
Native	< 0.001	0.945	0.709	< 0.001	0.991	0.613
Introduced	0.014	0.261	0.561	< 0.001	0.726	0.288
Total with Moss	< 0.001	0.993	0.885	< 0.001	0.831	0.497

Table A.2.11 P-values for Scheirer Ray Hare test for woody plant abundance.

	Soil	Woody Debris	Interaction
July 2008	< 0.001	0.556	0.225
August 2008	0.010	0.002	0.541
June 2009	0.375	0.001	0.236
August 2009	0.179	0.001	0.503

Table A.2.12 P-values for post hoc Mann-Whitney test to determine difference between woody debris treatments.

	Aspen x Spruce	Aspen x Control	Spruce x Control
August 2008	0.002	0.751	0.005
June 2009	0.002	0.686	0.001
August 2009	0.001	0.977	0.002

Table A.2.13 P-values for Scheirer Ray Hare test analyzing differences in species richness.

	Soil	Woody Debris	Interaction
July 2008			
Total	0.002	0.761	0.565
Native	0.002	0.881	0.613
June 2009			
Total	< 0.001	0.258	0.814
Native	< 0.001	0.327	0.798
August 2009			
Total	< 0.001	0.597	0.607
Native	< 0.001	0.547	0.458

Table A.2.14 P-values for t-test comparing proportion of plant groups growing near and away from woody debris in peat treatments.

	June 2009	August 2009
Cover		
Total	< 0.001	0.995
Vascular Plant	< 0.001	0.445
Moss	0.001	< 0.001
Native	0.220	0.794
Introduced	< 0.001	0.002
Biovolume		
Total	0.001	0.982
Native	0.424	0.534
Introduced	< 0.001	0.227
Woody Species		
Abundance	< 0.001	< 0.001
Cover	< 0.001	< 0.001
Biovolume	0.005	0.002
Salix Abundance	< 0.001	< 0.001

APPENDIX B. ADDITIONAL TABLES FROM CHAPTERS II AND III

Table B.1 List of species on four and two year old sites.

Species	Family	Common Name	Origin	Life Form
Grasses				
Agropyron repens (L.) Beauv.	Gramineae	Quackgrass	Introduced	Perennial
Agropyron trachycaulum (Link) Malte	Gramineae	Slender Wheatgrass	Native	Perennial
Agrostis scabra Willd.	Gramineae	Tickle Grass	Native	Perennial
Beckmannia syzigachne (Steud.) Fern.	Gramineae	Slough Grass	Native	Annual
Bromus tectorum L.	Gramineae	Downy Chess	Introduced	Annual
Calamagrostis canadensis (Michx.) Beauv.	Gramineae	Marsh Reed Grass	Native	Perennial
Cinna latifolia (Trev.) Griseb.	Gramineae	Drooping Wood Reed	Native	Perennial
Dactylis glomerata L.	Gramineae	Orchard Grass	Introduced	Perennial
Deschampsia cespitosa (L.) Beauv.	Gramineae	Tufted Hair Grass	Native	Perennial
Elymus innovatus Beal	Gramineae	Hairy Wild Rye	Native	Perennial
Glyceria grandis S. Wats. *ex* A. Gray	Gramineae	Manna Grass	Native	Perennial
Hordeum jubatum L.	Gramineae	Foxtail Barley	Native	Perennial
Koeleria macrantha (Ledeb.) J.A. Schultes f.	Gramineae	June Grass	Native	Perennial
Poa nervosa (Hook.) Vasey	Gramineae		Native	Perennial
Poa palustris L.	Gramineae	Fowl Bluegrass	Native	Perennial
Poa pratensis L.	Gramineae	Kentucky Bluegrass	Introduced	Perennial
Sedge				
Carex sp. L.	Cyperaceae	Sedge		Perennial
Forbs				
Achillea millefolium L.	Compositae	Common Yarrow	Native	Perennial
Artemisia biennis Willd.	Compositae	Biennial Sagewort	Native	Biennial
Aster ciliolatus Lindl.	Compositae	Lindley's Aster	Native	Perennial

Table B.1 List of species on four and two year old sites (continued).

Species	Family	Common Name	Origin	Life Form
Aster conspicuus Lindl.	Compositae	Showy Aster	Native	Perennial
Astragalus americanus (Hook.) M.E. Jones	Leguminosae	American Milk Vetch	Native	Perennial
Astragalus canadensis L.	Leguminosae	Canadian Milk Vetch	Native	Perennial
Cerastium vulgatum L.	Caryophyllaceae	Mouse Ear Chickweed	Introduced	Perennial
Chenopodium album L.	Chenopodiaceae	Lamb's Quarters	Introduced	Annual
Chenopodium capitatum (L.) Aschers.	Chenopodiaceae	Strawberry Blite	Native	Annual
Corydalis aurea Willd.	Fumariaceae	Golden Corydalis	Native	Biennial
Corydalis sempervirens (L.) Pers.	Fumariaceae	Pink Corydalis	Native	Biennial
Crepis tectorum L.	Compositae	Annual Hawksbeard	Introduced	Annual
Dracocephalum parviflorum Nutt.	Labiatae	American Dragonhead	Native	Annual, Biennial
Epilobium angustifolium L.	Onagraceae	Fireweed	Native	Perennial
Epilobium ciliatum Raf.	Onagraceae	Fringed Willowherb	Native	Perennial
Epilobium glandulosum (Lehm.) Hoch & Raven	Onagraceae		Native	Perennial
Erigeron canadensis L.	Compositae	Horseweed	Native	Annual
Fragaria vesca L.	Rosaceae	Woodland Strawberry	Native	Perennial
Fragaria virginiana Duchesne	Rosaceae	Wild Strawberry	Native	Perennial
Galium boreale L.	Rubiacese	Northern Bedstraw	Native	Perennial
Galium triflorum Michx.	Rubiacese	Sweet Scented Bedstraw	Native	Perennial
Geranium bicknellii Britt.	Geraniaceae	Bicknell's Cranesbill	Native	Annual, Biennial
Hieracium umbellatum L.	Compositae	Narrow Leaf Hawkweed	Native	Perennial
Kochia scoparia L. Schrad.	Chenopodiaceae	Summer Cypress	Introduced	Annual
Lactuca serriola L.	Compositae	Prickly Lettuce	Introduced	Annual
Lathyrus ochroleucus Hook.	Leguminosae	Cream Pea	Native	Perennial
Lathyrus venosus Muhl.	Leguminosae	Veiny Pea	Native	Perennial
Lepidium densiflorum Schrad.	Cruciferae	Common Pepperweed	Native	Annual
Maianthemum canadense Desf.	Liliaceae	Wild Lily of the Valley	Native	Perennial
Medicago sativa L.	Leguminosae	Alfalfa	Introduced	Perennial

Table B.1 List of species on four and two year old sites (continued).

Species	Family	Common Name	Origin	Life Form
Melilotus alba Desr.	Leguminosae	White Sweetclover	Introduced	Biennial
Mertensia paniculata (Ait.) G. Don	Boraginaceae	Tall Mertensia	Native	Perennial
Mitella nuda L.	Saxifragaceae	Bishop's Cap; Mitrewort	Native	Perennial
Moehringia lateriflora (L.) Fenzl.	Caryophyllaceae		Native	Perennial
Petasites palmatus (Ait.) A. Gray	Compositae	Palmate Leaved Coltsfoot	Native	Perennial
Petasites sagittatus (Pursh) A. Gray	Compositae	Arrow-leaved Coltsfoot	Native	Perennial
Plantago major L.	Plantaginaceae	Common Plantain	Introduced	Perennial
Polygonum aviculare L.	Polygonaceae	Prostrate Knotweed	Introduced	Annual
Polygonum lapathifolium L.	Polygonaceae	Knotweed	Native	Annual
Potentilla norvegica L.	Rosaceae	Rough Cinquefoil	Native	Annual, Biennial
Rubus pubescens Raf.	Rosaceae	Running Raspberry	Native	Perennial
Rumex occidentalis S. Wats.	Polygonaceae	Western Dock	Native	Perennial
Salsola kali L.	Chenopodiaceae	Russian Thistle	Introduced	Annual
Scenecio vulgaris L.	Compositae	Common Groundsel	Introduced	Annual
Solidago canadensis L.	Compositae	Goldenrod	Native	Perennial
Sonchus arvensis L.	Compositae	Perennial Sow Thistle	Introduced	Perennial
Stellaria longifolia Muhl.	Caryophyllaceae	Long-leaved Chickweed	Native	Perennial
Taraxacum officinale Weber	Compositae	Common Dandelion	Introduced	Perennial
Thalictrum venulosum Trel.	Ranunculaceae	Veiny Meadow Rue	Native	Perennial
Trientalis borealis Raf.	Primulaceae	Star Flower	Native	Perennial
Typha latifolia L.	Typhaceae	Common Cattail	Native	Perennial
Urtica dioica L.	Cannabinaceae	Common Nettle	Native	Perennial
Valeriana dioica L.	Fumariaceae	Valerian	Native	Perennial
Vicia americana Muhl.	Leguminosae	Wild Vetch	Native	Perennial
Viola adunca J.E. Smith	Violaceae	Early Blue Violet	Native	Perennial

Table B.1 List of species on four and two year old sites (continued).

Species	Family	Common Name	Origin	Life Form
Pteridophyte				
Equisetum arvense L.	Equisetaceae	Field Horsetail	Native	Perennial
Woody				
Amelanchier alnifolia Nutt.	Rosaceae	Saskatoon	Native	Perennial
Cornus sericea L.	Cornaceae	Red Osier Dogwood	Native	Perennial
Ledum groenlandicum Oeder	Ericaceae	Common Labrador Tea	Native	Perennial
Picea glauca (Moench) Voss	Pinaceae	White Spruce	Native	Perennial
Picea mariana (Mill.) BSP.	Pinaceae	Black Spruce	Native	Perennial
Populus balsamifera L.	Salicaceae	Balsam Poplar	Native	Perennial
Populus tremuloides Michx.	Salicaceae	Aspen	Native	Perennial
Potentilla fruticosa L.	Rosaceae	Shrubby Cinquefoil	Native	Perennial
Ribes glandulosum Grauer	Grossulariaceae	Skunk Currant	Native	Perennial
Ribes hudsonianum Richards.	Grossulariaceae	Wild Black Currant	Native	Perennial
Ribes lacustre (Pers.) Poir.	Grossulariaceae	Bristly Black Currant	Native	Perennial
Ribes oxyacanthoides L.	Grossulariaceae	Wild Gooseberry	Native	Perennial
Rosa acicularis Lindl.	Rosaceae	Prickly Rose	Native	Perennial
Rubus idaeus L.	Rosaceae	Wild Red Raspberry	Native	Perennial
Salix sp. L.	Salicaceae	Willow		Perennial
Shepherdia canadensis (L.) Nutt.	Elaeagnaceae	Canada Buffalo Berry	Native	Perennial
Spiraea alba Du Roi	Rosaceae	Narrow Leaved Meadowsweet	Native	Perennial
Symphoricarpos occidentalis Hook.	Caprifoliaceae	Buckbrush, Wolfberry	Native	Perennial

Table B.2 Mean soil properties from a 35 to 45 cm depth of B/C horizon under LFH cover. Samples were collected May 2008 for initial site characterization of the two year old site.

		LFH Total	Aspen	Spruce	Control
Available Nitrate	mg/kg	< 1.0	< 1.0	< 1.0	< 1.0
Available Phosphorus	mg/kg	5.6 (0.2)	6.0 (0.4)	5.5 (0.3)	< 5.0
Available Potassium	mg/kg	74.7 (2.5)	79.2 (5.1)	72.5 (2.8)	70.0 (4.5)
Available Sulphate	mg/kg	49.0 (22.1)	68.5 (54.1)	38.3 (13.5)	31.5 (12.8)
C:N		32.8 (1.7)	36.1 (3.6)	31.3 (1.8)	29.3 (1.5)
Total Organic Carbon	%	1.68 (0.09)	1.75 (0.13)	1.71 (0.16)	1.47 (0.08)
Total Nitrogen	%	0.07 (0.02)	0.05 (0.00)	0.11 (0.06)	0.05 (0.00)
Sand	%	51.6 (0.7)	52.6 (1.2)	51.2 (1.0)	50.2 (1.7)
Silt	%	29.0 (0.4)	29.2 (0.7)	28.2 (0.7)	30.3 (1.0)
Clay	%	19.4 (0.7)	18.2 (1.0)	20.6 (1.0)	19.4 (1.6)
pH		6.5 (0.1)	6.5 (0.2)	6.7 (0.1)	6.3 (0.3)
Electrical Conductivity	dS/m	0.90 (0.18)	0.99 (0.42)	0.87 (0.15)	0.77 (0.19)
Sodium Adsorption Ratio		1.0 (0.3)	1.2 (0.7)	0.9 (0.3)	1.0 (0.5)

Numbers are means followed by standard errors in brackets.
LFH n = 30, Aspen n =12, Spruce n = 12, Control n = 6.

Table B.3 Mean soil properties from a 35 to 45 cm depth of clean overburden horizon under peat cover. Samples were collected May 2008 for initial site characterization of the two year old site.

		Peat Total	Aspen	Spruce	Control
Available Nitrate	mg/kg	2.2 (0.2)	2.5 (0.5)	2.2 (0.4)	1.7 (0.3)
Available Phosphorus	mg/kg	5.2 (0.2)	< 5.0	< 5.0	6.0 (1.0)
Available Potassium	mg/kg	85.0 (7.0)	91.7 (12.2)	86.7 (12.2)	68.3 (7.8)
Available Sulphate	mg/kg	196.2 (33.6)	206.6 (49.3)	215.1 (66.8)	137.7 (38.8)
C:N		55.8 (2.57)	52.5 (3.9)	57.8 (4.4)	58.3 (5.6)
Total Organic Carbon	%	2.87 (0.15)	2.70 (0.19)	3.01 (0.30)	2.92 (0.28)
Total Nitrogen	%	0.07 (0.01)	0.05 (0.00)	0.09 (0.04)	< 0.05
Sand	%	57.5 (0.7)	56.6 (1.1)	57.1 (1.1)	60.1 (1.2)
Silt	%	24.3 (0.4)	24.9 (0.6)	23.8 (0.5)	24.1 (1.1)
Clay	%	18.2 (0.6)	18.5 (0.9)	19.1 (1.1)	15.8 (0.7)
pH		7.6 (0.1)	7.6 (0.0)	7.5 (0.0)	7.8 (0.3)
Electrical Conductivity	dS/m	2.04 (0.25)	2.24 (0.42)	2.09 (0.45)	1.54 (0.32)
Sodium Adsorption Ratio		4.0 (0.8)	4.6 (1.3)	4.5 (1.4)	2.0 (0.7)

Numbers are means followed by standard errors in brackets.
Peat n = 30, Aspen n =12, Spruce n = 12, Control n = 6.

Table B.4 Mean available nitrate and phosphorus from a 0 to 5 cm depth in August 2009 from the two year old site.

		Cover		Woody Debris				
		LFH	Peat	Aspen Large	Aspen Small	Spruce Large	Spruce Small	Control
Available Nitrate	mg/kg	2.0 (0.0)	2.8 (0.6)	< 2.0	< 2.0	< 2.0	2.1 (0.1)	3.9 (1.6)
Available Phosphorus	mg/kg	48.2 (3.2)	39.1 (4.0)	49.4 (8.3)	42.1 (3.1)	44.9 (4.6)	49.8 (6.4)	32.0 (5.0)

Numbers are means followed by standard errors in brackets.

Cover n = 30, Woody debris n = 12.

Table B.5 Mean monthly temperature (ºC) and total monthly rainfall (mm) from 2007 to 2009 for the steepbank north dump, location of the nearest climate station to both research sites.

	2007		2008		2009	
	Mean Monthly Temperature (ºC)	Monthly Total Rainfall (mm)	Mean Monthly Temperature (ºC)	Monthly Total Rainfall (mm)	Mean Monthly Temperature (ºC)	Monthly Total Rainfall (mm)
January	-13.0	0.0	-17.0	0.0	-18.2	0.0
February	-17.9	0.0	-16.8	0.0	-14.6	0.0
March	-7.5	4.3	-7.7	3.3	-9.6	0.0
April	4.2	23.4	0.5	1.5	3.7	16.8
May	11.8	9.7	12.1	4.8	8.6	12.2
June	16.0	14.7	17.4	71.1	15.8	84.1
July	21.8	41.9	18.5	58.9	17.4	25.4
August	14.3	72.9	17.6	102.6	16.9	59.7
September	9.1	20.3	10.3	17.5	15.1	12.2
October	5.7	4.6	6.2	40.9	1.7	0.8
November	-6.5	0.3	-3.1	10.4	-2.7	0.0
December	-15.5	0.0	-21.4	4.3	-18.0	0.0
Total	1.9	192.1	1.4	315.5	1.3	211.1
Growing Season Total	16.0	139.2	16.4	237.5	14.7	181.4

APPENDIX C. CALIBRATION EQUATIONS FOR SOIL VOLUMETRIC WATER

The HOBO system outputs volumetric water content (VWC) data calculated from a linear default equation for sandy loam soils. A calibration equation was needed to calibrate HOBO data to accurately represent the peat mineral mix (peat) and upland surface soil (LFH) covers used on the two year old site. O'Kane Consultants, Inc. formed second order polynomial equations based on their experience in the oil sands and on data from this study, extending over a year. Maximum and minimum recorded values were used to approximate field capacity and residual water content. A default equation was used on the raw VWC data to extract the raw mV data. Then a material specific equation was used to calibrate the raw mV data into VWC data specific to cover type. Equations are as follows:

(a) Upland forest soil (LFH)

Default equation: mV data = (raw VWC – B) / M

Where B = -0.327 and M = 0.000682

Material Specific Equation

Calibrated VWC = C_2 * (mV data)^2 + C_1 * (mV data) + C_0

Where C_2 = -0.00000051, C_1 = 0.00144, and C_2 = -0.54

(b) Peat mineral mix cover soil (peat)

Default equation: mV data = (raw VWC – B) / M

Where B = -0.327 and M = 0.000682

Material Specific Equation

Calibrated VWC = C_2 * (mV data)^2 + C_1 * (mV data) + C_0

Where C_2 = -0.00000198, C_1 = 0.00423, and C_2 = -1.5718