Soil microbial communities in northern Alberta's boreal forest floors following resource extraction

by

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A thesis submitted in partial fulfillment of the requirements for the degree of

Master of Science

in

Soil Science

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ABSTRACT

Land disturbance linked to resource extraction in Alberta ranges in severity from full ecosystem removal during surface mining to more surficial disturbance during clearcut timber harvesting. Changes to these ecosystems affect the soil microbial community, and the health of boreal forests is largely dependent on the soils in which they grow. Microbial communities are responsible for the decomposition and mineralization of forest litter, which converts major nutrients to useable forms for vegetation, thereby cycling the nutrients through the ecosystem. Phospholipid fatty acid (PLFA) and multiple substrate induced respiration (MSIR) analyses were used to assess the structural and functional diversity of forest floor soil microbial communities in two disturbed boreal forest ecosystems: (1) in a clearcut harvested stand 17.5 years post-harvest, and (2) in a 31 year chronosequence of reclaimed soils following surface mining. Disturbed stands were compared to their undisturbed counterparts in both forest ecosystems. In the harvested area, trembling aspen (*Populus tremuloides*) was the dominant tree species regenerating in both aspen and spruce (*Picea glauca*) clearcuts. PLFA and MSIR analyses demonstrated the importance of aspen stand regeneration on spruce clearcuts and its influence on soil properties. In both clearcuts, microbial communities exhibited comparable functional diversity, and a structure more similar to the communities in undisturbed aspen forest floors than undisturbed spruce. In the surface mined area, the novel forest floor that developed atop the peat-mineral coversoil was key to the reestablishment of a microbial community with different structure, yet similar biomass and function to that present in undisturbed soils.

ACKNOWLEDGEMENTS

This thesis is the culmination of the knowledge and experience I gained over the past seven years of undergraduate and graduate study at the University of Alberta. I wouldn't have made it here today without the support of many wonderful people in my life. To David, thank you for supporting my decision to go to school and backing me up every step of the way. You saw my potential in the beginning and reminded me of it whenever I doubted myself. To my parents, Alma and Jim, thank you for your countless pep talks, dinners, and walks with the dogs. You have created a home where I can go to let the stress melt away. To my brothers, sister-in-laws, nieces, and nephews thank you for reminding me to have fun outside of school.

To Dr. Sylvie Quideau, thank you for sending me to Fort McMurray and awakening my love for reclamation. You convinced me I was capable of an MSc, and were patient and kind throughout. Thank you for teaching me about research and writing. I will be forever grateful. Thank you to Dr. Mathew Swallow for our countless conversations on soil science and of course our love of dogs. Thank you to Dr. Miles Dyck for being a part of my examination committee.

To my fellow MSc ladies, Brittany McAdams and Sarah Thacker, thank you for your friendship, help in the field, and constant support through all the steps of the master's program. To my colleagues, Preston Sorenson, Dr. Karen Thompson, Dr. Frédéric Rees, Paul Sewell, Jela Burkus, Shelby Buckley, and Katelyn Pretzlaff, thank you for your help over the years.

Finally, I would like to thank the Natural Sciences and Engineering Research Council of Canada, the Environmental Reclamation Research Group (ERRG) of the Canadian Oil Sands Network for Research and Development (CONRAD), and the EMEND partners - Daishowa-Marubeni International, Canfor, the Government of Alberta's Ministry of Agriculture and Forestry, and the University of Alberta for your funding and support.

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LIST OF SYMBOLS AND ABBREVIATIONS

AOSR	Athabasca oil sands region
EMEND	Ecosystem management emulating natural disturbance project
FF.PMM-Mid&Mat	Forest floor - peat-mineral soil mix from mid and mature aged stands
FF.PMM-Yg.	Forest floor and peat-mineral soil mix from young reclaimed stands
LOS	Lean oil sand
Novel.FF	Novel forest floor
OB	Overburden
PMM	Peat-mineral soil mix
TC	Total carbon
TN	Total nitrogen

1. CHAPTER 1 – GENERAL INTRODUCTION

Land disturbance linked to resource extraction in Alberta ranges in severity from full ecosystem removal during surface mining in the Athabasca oil sands region (AOSR) to more surficial disturbance during timber harvesting (Hannam et al., 2006; Johnson and Miyanshini, 2008). In all cases, changes to these terrestrial ecosystems affect the soil microbial community. Soil microorganisms are vital to the biogeochemical cycling of major nutrients between soils and vegetation (Quideau et al., 2013). A sustainable soil capable of supporting a thriving forest is dependent upon a diverse soil microbial community functioning to decompose forest litter and cycle the nutrients through the ecosystem (Visser et al., 1983). Consequently, understanding the effects of resource extraction and current regeneration practices on soil biodiversity is essential to ensuring the long-term sustainability of our forest ecosystems.

1.1 The boreal forest

The boreal forest serves as a substantial terrestrial carbon reservoir, storing 32% of global carbon with 20% in above-ground biomass and 60% in soil (Pan et al. 2011). Consequently, managing resource extraction to minimize degradation of boreal forest soils is of utmost importance to carbon retention. In the boreal forest, regeneration following natural disturbance such as fire generally progresses from broadleaf- to mixed to conifer-dominated forests (Macdonald et al., 2010). Bergeron et al. (2014) outline five alternative pathways to the classical successional trajectory following natural disturbance in boreal mixedwood forests: (i) continual broadleaf dominance resulting in multi-aged aspen stands (ii) continual recruitment of broadleaf and conifer resulting in multi-aged mixedwood stands, (iii) accelerated conifer replacement, resulting in quick mixedwood to conifer transition (iv) broadleaf recruitment in gaps resulting in conifer to mixedwood transition, and (v) broadleaf or conifer transition to shrubs. The pathway taken depends on interactions between the species present, environmental conditions, and disturbance frequency and severity (Cattelino et al., 1979). For example, the classic successional trajectory requires the ability of coniferous species to develop under the deciduous canopy. This depends on seed availability (Johnstone and Chapin, 2006), seedbeds of mineral soil, decayed wood, or a thin organic layer (Purdy et al., 2002; Peters et al., 2006), microsites with proper light and moisture (Zoladeski and Maycock, 1990; Zasada et al., 1992), and understory competition (Bergeron et al., 2014). If site conditions do not promote conifer regeneration, deciduous stands may self-replace through root suckers (Dix and Swan, 1971; Schier 1973; Frey et al., 2003; Johnstone and Chapin 2006).

Numerous studies have documented the influence of different boreal tree species on soil characteristics (Saetre and Bååth, 2000; Aponte et al., 2013; Quideau et al., 2013; Pei et al., 2016). For example, pioneer tree species (i.e., aspen) with rapid growth rates return carbon and nitrogen to the soil quickly as the stand develops and litter falls (Carnol and Bazgir, 2013; Prescott and Vesterdal, 2013). These litter inputs affect microbial biomass and structure through increased carbon (Schutter and Dick, 2001; Frouz et al., 2013, Hansson et al., 2013), and nitrogen stocks (Cote et al., 2000; Lindo and Visser, 2003), and contribute to changes in soil pH (Priha et al., 2001; Hannam et al., 2006). Tree type also influences soil microclimate by affecting temperature through canopy morphology (Hannam et al. 2007), and moisture through canopy interception of precipitation and transpiration (Sprenger et al. 2013). There is also variation in the quantity and quality of root exudates based on tree species, which promotes mycorrhizal fungi associations and the development of microbial communities (Grayston and Campbell, 1996; Hannam et al. 2007; Prescott and Grayston, 2013).

1.2 Alberta timber harvesting

Canada is home to 10% of global forests, making Canada a world leader in harvested wood products (Chen et al., 2014). Ninety-four percent of Canada's forests are on publicly owned land, therefore provinces and territories are responsible for making and enforcing laws regarding forestry operations and harvesting practices. Private forestry companies are granted the right to harvest on public lands, however they must create and follow a forest management plan that has been approved by the government. In addition, all harvested areas must be replanted or permitted to naturally regrow. In 1992, the Canadian Council of Forest Ministers endorsed the adoption of sustainable forest management (SFM). Natural Resources Canada claims SFM ensures the health of Canada's forests while balancing environmental, economic, and social benefits (NRC, 2016). The health of Canada's forests is largely dependent on the soils in which they grow. Harvesting is generally conducted when the ground is frozen to minimize disruption to the forest floor. However, harvesting temporarily removes nutrients from the ecosystem and disrupts nutrient cycling (Foster and Bhatti, 2006) Consequently, understanding the effects of harvesting on soil microbial community function is paramount to SFM.

For the second chapter of my thesis, I conducted work at the Ecosystem Management Emulating Natural Disturbance (EMEND) project, which is an experimental site located 90 km northwest of Peace River, Alberta, Canada (56° 46' 13" N, 118° 22' 28" W), in the Clear Hills Upland Ecoregion of the Boreal Plains Ecozone (Wiken, 1986; Ecoregions Working Group, 1989). The site covers 1000 ha of the boreal mixedwood forest with dominant tree species including trembling aspen, balsam poplar (*Populus balsamifera* L.) and white spruce. Soils at EMEND are largely Orthic Gray and Dark Gray Luvisols (Soil Classification Working Group, 1998; Kishchuk, 2004). They formed on fine-textured glaciolacustrine and glacial till parent geological materials, with the dominant soil forming process being the eluviation/illuviation of clay (i.e., lessivage). The soils contain few coarse fragments and are typically well drained (Kishchuk, 2004).

The EMEND project is a long-term experiment designed, in part, to examine forest regeneration, patterns of succession, and biodiversity in four forest cover types. Harvesting treatments were applied to 10 ha compartments within the four cover types in the winter of 1998-1999. Treatments include undisturbed controls, clearcut harvest, and retention harvests of 10%, 20% and 50%. The experiment began in 1988 and is expected to run for 80-100 years (one stand rotation). My study follows work conducted by K.D. Hannam at EMEND comparing undisturbed, clearcut, 20% and 50% retention four years' post-harvest to determine how soil microbial structure and function developed in undisturbed and post-logged soils of stands dominated by trembling aspen, white spruce, and mixedwoods of aspen and spruce (Hannam *et al*., 2006). In 2003-2004, K.D. Hannam sampled the forest floor of three 10 ha replicates each of undisturbed and clearcut aspen and spruce dominated stands (a total of 12 experimental units). In the present study, we sampled 10 of Hannam's experimental units and two new ones, as Hannam's could not be accessed due to a bridge failure. Therefore, the present study covered a similar variation within the EMEND landscape. Aspen dominated stands contained > 70% trembling aspen mixed with some balsam poplar (*Populus balsamifera* L.). White spruce dominated stands contained > 70% white spruce with some trembling aspen, balsam poplar, paper birch, balsam fir (*Abies balsamea* (L.) Mill.) and lodgepole pine (*Pinus contorta* Dougl. ex Loud.) in decreasing order of abundance (Hannam et al. 2006; Kishchuk et al. 2014). Following Hannam's work allows for the comparison of soil microbial structure and function 6 years post-harvest to 17 years post-harvest.

1.3 Athabasca oil sands

Oil sands are a naturally occurring mixture of sand grains, clay, silt, bitumen and water. Bitumen is a viscous petroleum hydrocarbon that must be extracted from the oil sands and processed to create crude oil. Alberta's oil sand reserves are the second largest in the world and are estimated to hold up to 1.7 trillion barrels of bitumen (Alberta Government [GoA], 2009). There are four major oil sands deposits in northern Alberta know as Athabasca, Wabasca, Cold Lake and Peace River, which cover 142,200 km^2 (Fung and Macyk, 2000). My research focuses on the largest deposit in the Athabasca region covering 4800 km^2 (seven times the size of the city of Edmonton). Approximately 20% of the reserves in this region are close enough to the surface to be recovered through surface mining. Surface mining involves excavation of native soils and underlying geological deposits (up to 80 m depths), which have taken thousands of years to develop (Fung and Macyk, 2000; GoA, 2009). The result is severed ecosystem processes between the vegetation, soil, and groundwater.

Prior to disturbance mined areas were largely lowland ecosystems dominated by black spruce (*Picea mariana* (Mill.) BSP) and tamarack (*Larix laricina* (Du Roi) K. Koch). However, reclamation efforts in the Athabasca oil sands region (AOSR) are converting some of these areas to upland forests dominated by trembling aspen (*Populus tremuloides* Michx.) and white spruce (*Picea glauca* (Moench) Voss) (Fung and Macyk, 2000; MacKenzie and Quideau, 2010). Natural soils in the area have developed on till, fluvial and lacustrine parent geological materials deposited during the Wisconsin glaciation 70 000 to 10 000 years ago (Crown and Twardy, 1970). Typic Fibrisols and Orthic Gleysolic soils are found in lowlands, while Dystric Brunisols and Gray Luvisolic soils are found upland (Crown and Twardy, 1970).

During the excavation process in the AOSR, a range of materials are salvaged within the lease development area, and are subsequently used during land reclamation. The primary goal of soil reconstruction following mining is to provide an adequate cover design and capping thickness to achieve an equivalent land capability to pre-disturbance conditions. Reconstructed soils typically consist of two layers, including a subsoil overlain by a coversoil consisting of either surface soil (LFH, A, and potentially part of the B horizons) salvaged from upland forests, or peat material salvaged from wetlands (GoA, 2009; Sorenson et al., 2011; Quideau et al., 2013). A peat coversoil, which is the most common coversoil in the AOSR, is the surface organic material salvaged from peatland bogs and fens. Depending on the amount of underlying mineral soil salvaged and mixed in with the peat, it is classified as peat (≥17% total organic carbon) or peat-mineral mix (PMM; <17% total organic carbon).

For the third chapter of my thesis, twenty experimental sites were chosen in the AOSR with similar slope, reclamation prescription (PMM) and climate so that the effects of vegetation and time could be isolated. These experimental sites are located 35-68 km north of Fort McMurray, Alberta, Canada (56° 43' 34" N, 111° 22' 49" W), in the Wabasca Lowland Ecoregion of the Boreal Plains Ecozone (Wiken, 1986; Ecoregions Working Group, 1989). Fifteen reclaimed sites on Syncrude and Suncor mining leases form a chronosequence of years since reclamation, including three young reclaimed replicates (8-11 yrs). Five sites planted to aspen include three mid reclaimed replicates (17-27 yrs) and two old reclaimed replicates (30-31 yrs). Seven sites planted to spruce consist of four mid reclaimed replicates (23-25 yrs) and three old reclaimed replicates (30-31yrs). Five undisturbed sites (3 aspen and 2 spruce 35-103 yrs) will allow comparison of microbial processes in reclaimed and undisturbed soils, and to analyze whether reclaimed soils evolve towards their undisturbed analogs with time since reclamation.

1.4 Characterization of soil microbial communities

Total microbial biomass and the overall structure of the microbial community can be characterized using phospholipid fatty acid (PLFA) analysis (Bligh and Dyer, 1959; White and Ringelberg, 1998). The cell membranes of the domains *Bacteria* and *Eukarya* are partially made up of phospholipid fatty acids (PLFAs). Each fatty acid tail is composed of carbon atoms, and the length and structure of the tails serve as biomarkers of the soil microbial community. Classes of soil microbes typically have tails of 14 – 20 carbon atoms. During extraction, the fatty acid tails are separated from the phospholipid head and the individual fatty acids are identified using a gas chromatograph. PLFA analysis cannot identify soil microorganisms to the species level, however it can tell us what proportion of the microbial community is made up of the domains *Bacteria* and *Eukarya*. *Bacteria* includes actinomycetes and gram-positive, gram-negative, sulfate-reducing and methanogenic bacteria. *Eukarya* includes fungi, algae and protists.

Microbial community structure may change in response to stress, therefore PLFA profiling serves as a biological index of soil quality and a quantitative indicator of microbial response to environmental stressors (Dimitriu et al., 2010; Sorenson et al., 2011; Quideau et al., 2016). PLFA analyses have been used to study soil microbial structure and function in many different soil ecosystems. More specifically, with regards to monitoring soil recovery following oil sands disturbance, results from PLFA analysis have indicated that microbial communities on reclaimed soils, at least initially, are structurally different from communities on natural boreal soils (Dimitriu et al., 2010; Hahn and Quideau, 2013). In comparison, effects due to clearcutting are much reduced, especially when disturbance to the forest floors is minimized (Hannam et al., 2006).

The functional diversity of the microbial communities can be determined using multiple substrate induced respiration (MSIR) analysis. The SIR method described by Degens and Harris (1997) has been modified to use a whole-soil approach (Swallow, 2015). MSIR characterizes the functional diversity of microbial communities by measuring the catabolic response of the whole community to a range of carbon substrates (Peham and Bruckner, 2012). Chosen substrates, such as root exudates (e.g.; L-threonine, malonic acid) are meant to represent those naturally found in the soil of interest. Substrates are also chosen for their ability to discriminate between different sites, and should span the variety of chemical structures found in soils, including amines (e.g., N-acetyl glucosamine), carbohydrates (e.g., D-cellobiose), carboxylic acids (e.g., malonic, pantothenic and quinic acids) and aromatics (e.g., syringic acid) (Stevenson et al, 2004; Lalor and Cookson, 2007; Peham and Bruckner, 2012). Substrates are added to soil samples and left to incubate to allow the microbes to metabolize the substrates. As the microbes respire, agar detection plates change colour in response to CO_2 adsorption. The amount of CO_2 produced represents the catabolic response of the whole microbial community. To date, little is known about how specific biogeochemical processes may recover in boreal soils following disturbance. Clearly, these fundamental processes, including the functional diversity of soil microbial communities, need to be quantified so that scientifically based land management strategies can be developed to conserve and enhance our boreal forests ecosystems.

1.5 Research objectives and hypotheses

For this MSc thesis, I characterized the structural and functional diversity of soil microbial communities in chronosequences of soils disturbed by both surface mining and clearcut timber harvest. I examined how tree cover may influence soil microbial function by comparing stands dominated by trembling aspen and white spruce. In addition, I sampled undisturbed soils in the vicinity of the surface mined and clearcut areas (supporting either aspen or white spruce stands) to compare microbial processes in disturbed and undisturbed soils, and to analyze whether disturbed soils evolve towards their undisturbed analogs with time since disturbance. The results of this study will contribute to our understanding of boreal forest recovery following resource extraction by quantifying the functional biodiversity of the belowground compartment. The specific objectives were to: (1) examine how tree cover influenced soil microbial structure and function, and (2) examine how disturbance type (surface mining vs. clearcut harvesting) influenced soil microbial structure and function.

I hypothesized that undisturbed aspen forests would have a greater microbial biomass than spruce forests, and that the two forests would harbor different soil microbial communities due to the differences in tree litter quality. I also hypothesized that higher severity disturbance (mining) would result in lower microbial biomass, and a greater change in function than clearcutting due to a more severe change of environment; however, under both disturbance regimes, the microbial community should adapt to their new surroundings and evolve towards the undisturbed communities with time. Lastly, I hypothesized that microbial recovery would proceed at a faster rate under more rapid growing aspen than under spruce, and that the functional diversity of soil microbes would evolve parallel to tree establishment.

2. CHAPTER 2 – FOREST FLOOR MICROBIAL COMMUNITIES FOLLOWING TIMBER HARVEST

2.1 Introduction

The forest floor is essential to boreal ecosystem function. It is a repository of native plants seeds and nutrients (Pare et al., 1993; Macdonald et al., 2011), it stores and purifies water (Prescott et al., 2000), provides energy for biogeochemical cycling (Bashkin, 2003; Swallow and Quideau, 2013), and is the major site of soil microbial activity (Foster and Bhatti, 2006). Tree species affect the structure and function of forest floor microbial communities through the quantity and quality of litterfall and root exudates (Lindo and Visser, 2003; Grayston and Campbell, 1996; Carnol and Bazgir, 2013), and the soil microclimate (Hannam et al., 2007; Prescott and Vesterdal et al., 2013). Forest floors formed from deciduous litter can have higher nutrient levels, pH, and microbial biomass compared to coniferous litter (Priha et al., 2001; Lindo and Visser, 2003; Hannam et al., 2006).

Home to 10% of global forests, Canada is a world leader in harvested wood products (Chen et al., 2014). However, Canada has a very short history of boreal forest management compared to Fennoscandian countries, as most of Canada's cuts are still first rotation. Ensuring the sustainable management of Canadian forests for future generations requires empirical knowledge of their recovery trajectory following harvest, specifically regarding soil microbial communities, which are essential to biogeochemical cycling and forest productivity. In the boreal mixedwood region of Canada, regeneration following natural disturbance such as fire generally progresses from broadleaf- to mixed to conifer-dominated forests (Macdonald et al., 2011) with distinct microbial communities associated with each stand type (Prescott and Vesterdal, 2013). In the boreal mixedwood forests of northern Alberta, the "classic" successional trajectory following fire begins with stands dominated by fast-growing, shade-intolerant trembling aspen (*Populus tremuloides* Michx). When mature aspen begins to senesce, canopy openings allow for stand transition to slower-growing shade-tolerant, white spruce (*Picea glauca* [Moench.] Voss.) dominated stands (Rowe, 1956; Bergeron *et al*., 2014). However, stand dynamics of the boreal mixedwood forest reflect complex interactions between many biotic and abiotic factors, resulting in a wide variation of post-disturbance stand development pathways (Cattelino et al., 1979; Bergeron et al., 2014).

Stand dynamics following natural disturbance are highly variable, and that variability increases with forest harvest and regenerative practices on the landscape. To maintain biodiversity and ecosystem integrity researchers and land managers must work together to understand vegetation dynamics and stand regeneration following harvest. The Ecosystem Management Emulating Natural Disturbance (EMEND) project in the boreal mixedwood region of northwestern Alberta, Canada is a long-term experiment designed, in part, to examine forest regeneration, patterns of succession, and biodiversity in four forest cover types. The EMEND project is a fully replicated 4x8 factorial experiment with harvesting treatments applied to 10 ha compartments within the four cover types. Treatments include undisturbed controls, clearcut harvest, and retention harvests of 10%, 20%, 50%. The experiment began in 1998 and is expected to run for one stand rotation, approximately 80 -100 years. The present study follows work conducted by K.D. Hannam at EMEND comparing undisturbed, clearcut, 20% and 50% retention five years post-harvest to determine how soil microbial structure and function developed in undisturbed and post-logged soils of stands dominated by trembling aspen, white spruce, and mixedwoods of aspen and spruce (Hannam et al., 2006).

Hannam et al. (2006) reported no effect of harvesting on soil microbial biomass, community structure, or function in the three stand types five years post-harvest. However, in undisturbed stands, there were strong differences in soil microbial biomass and community structure between aspen and spruce stands. The present study focuses on undisturbed and clearcut stands dominated by either trembling aspen or white spruce. The aims of this study were to assess stand dynamics 17.5 years post-harvest, and to determine if (i) microbial biomass, structure and function differed between the two undisturbed stand types, (ii) microbial biomass, structure and function of clearcut harvest stands resembled those of undisturbed stands, and (iii) microbial biomass, structure and function varied between the two post-harvest stand types.

2.2 Materials and Methods

2.2.1 Study area and site selection

The EMEND experimental site (<www.emendproject.org>) is located 90 km northwest of Peace River, Alberta, Canada (56° 46' 13" N, 118° 22' 28" W), in the Clear Hills Upland Ecoregion of the Boreal Plains Ecozone (Wiken, 1986; Ecoregions Working Group, 1989). Depressional to undulating topography results in elevation ranges from 677 to 880 m.a.s.l. in a northwest to southeast direction over approximately 8 km (Lindsay et al., 1958; Kishchuk, 2004). The climate is characterized by long cold winters and cool short summers. The mean monthly air temperature ranges from -16.9˚C in January to 15.0˚C in July. The mean annual precipitation is 436.2 mm with rainfall accounting for 307.4 mm during the growing season (Environment Canada, 2015b). Soils at EMEND are largely Orthic Gray and Dark Gray Luvisols (Soil Classification Working Group, 1998; Kishchuk, 2004). The Luvisols have formed on fine-textured glaciolacustrine and glacial till parent geological materials, with the dominant soil forming process being the eluviation/illuviation of clay (i.e., lessivage). The soils contain few coarse fragments and are typically well drained (Kishchuk, 2004).

The EMEND experimental site covers 1000 ha of the boreal mixedwood forest, and has been divided into 10 ha stands that are deciduous dominated, primarily trembling aspen, stands that are coniferous dominated, primarily white spruce, and mixedwood stands dominated by both aspen and spruce. Three major fire events in 1837, 1895 and 1977 have resulted in stands ranging in age from 121 to 179 years (Bergeron, 2012). The most common understory shrubs across the experimental sites are low bush cranberry (*Viburnum edule* (Michx.) Raf.), prickly rose (*Rosa acicularis* Lindl.), Canada buffaloberry (*Sheperdia Canadensis* (L.) Nutt.), green alder (*Alnus crispa* (Ait.) Turrill), and river alder (*Alnus tenufolia* Nutt.) Forest floors in aspen stands were classified as Mormoders, and spruce stands as Humimors (Hannam et al., 2006).

The clearcuts were harvested in the winter of 1998-1999 to minimize soil disturbance. A feller-buncher harvested whole trees and skidded them directly to the landing where stems were de-limbed and debris burned. No site preparation occurred prior to natural regeneration of the vegetation. In 2003-2004, K.D. Hannam sampled the forest floor of three 10 ha replicates each of undisturbed and clearcut aspen and spruce dominated stands (a total of 12 experimental units). In the present study, we originally chose to sample the same three 10 ha replicates each of undisturbed and clearcut aspen and spruce dominated stands. However, two of the 10 ha compartments sampled in Hannam's study, one each of undisturbed and clearcut spruce, could not be accessed due to a bridge failure. Therefore, the present study sampled 10 of Hannam's experimental units and two new experimental units so that both studies covered stands across the 1000 ha EMEND experimental site. For the current study, the forest floor was sampled within three random plots established within each 10 ha replicate, resulting in 36 independent sampling units.

2.2.2 Vegetation survey and soil collection

The 36 sampling units were described and sampled in June 2016. For each unit a centre point was selected and four subsampling locations identified 5 m from the centre point in the four cardinal directions to create a 100 m^2 plot. Several vegetation characteristics were described within a 0.25 m^2 area around each of the four subsampling locations; these included: leaf area index (LAI); dominant tree, shrub and forb species; and ground cover (%) of lichen, moss, leaf litter, spruce needles, coarse woody debris and shrubs (Royer and Dickinson, 2007). LAI was described as defined by Marshall and Waring (1986) as the total surface area of leaves per unit of ground area, and was measured with a Licor 2200 30 cm from the ground. Within the 100 m^2 plots, measurements included: slope, aspect, sampling distance to nearest tree, and dominant tree diameter at breast height (DBH).

At each of the four subsampling locations, the entire depth of the forest floor was sampled unless it was > 10 cm thick, in which case only the top 10 cm was sampled. At each of the four subsampling locations a bulk density sample was collected with a 10 x 10 cm square. Next to the bulk density samples, two independent homogenized samples of the four subsampling locations were collected to create two forest floor samples representative of each sampling unit. Soil temperature was recorded at a depth of 5 cm. All samples were kept cool on ice during transport. Upon return to base camp the four bulk density samples were air dried. Large roots and chunks of wood were removed from the two independent homogenized samples. One homogenized sample was for multiple substrate induced respiration (MSIR) characterization. The other homogenized sample was split into two samples: one for phospholipid fatty acid (PLFA) analysis, and one for pH, total carbon and nitrogen. The sample for pH, total carbon and nitrogen was left out to air dry, and the MSIR and PLFA samples were stored at -20˚C within 12 hours. Upon return to the laboratory, PLFA samples were stored at -86˚C, then freeze dried prior to extraction.

2.2.3 Laboratory analyses

The subsamples collected within the 10 x 10 cm square were weighed before air drying at base camp. Upon return to the laboratory they were oven dried at 65˚C for 48 hours and weighed again to determine bulk density and gravimetric water content and. For pH, 0.01 *M* calcium chloride was added to air-dried forest floors using a 1:4 soil:solution dilution ratio (Kalra and Maynard, 1991). For total carbon and nitrogen determination, samples were air dried, ground with a Retsch MM200 ball mill grinder, then analyzed by flash combustion on a Costech Model EA 4010 Elemental Analyzer (Costech International Strumatzione, Florence, Italy, 2003). For total carbon and nitrogen and stable isotope ^{13}C and ^{15}N determination, samples were air dried, and ground as described above, then analyzed by flash combustion on a ThermoFinnigan Delta Advantage Continuous Flow Isotope Ratio Mass Spectrometer (Thermo Finnigan Corp, Bremen, Germany, 2003). Results were expressed in the δ-notation, part per thousand variations from the standards, Pee Dee Belemnite (PDB) for carbon and atmospheric N_2 for nitrogen.

Phospholipid fatty acid (PLFA) analysis was used to estimate total microbial biomass and the structural composition of soil microbial communities. Quideau et al. (2016) comprehensively describes the protocol used. In short, polar lipids were extracted from 0.7 g freeze dried soil using a modified Bligh and Dyer (1959) process. Polar lipids were purified on pre-packed silica columns (Agilent Technologies, Wilmington, DE, USA), and then treated to mild alkaline methanolysis to form fatty acid methyl esters (FAMEs), which were quantified using an Agilent

6890N Series capillary gas chromatograph (Agilent Technologies, Wilmington, DE, USA). Fatty acid peaks were identified using the Sherlock Microbial Identification System Version 6.3 (MIDI, Inc., Newark, DE) and described with the standard X:YωZ nomenclature where X indicates the number of carbon atoms, Y the number of double bonds, and Z the location of the first double bond from the aliphatic (ω) end of the molecule. The 'c' and 't' suffixes denote cis and trans geometric isomers. The prefixes 'a', 'i' and Me indicate anteiso and iso branching and methyl groups.

Multiple substrate induced respiration (MSIR) measurements characterized the functional diversity of the soil microbial communities, by measuring the catabolic response of the community to a range of substrates (Peham and Bruckner, 2012). Swallow and Quideau (2015) thoroughly describe the MSIR protocol used. Briefly, the Degens and Harris (1997) method was modified to use a whole-soil approach. The seven substrates administered are naturally found in soils and root exudates, and were chosen for their ability to discriminate between different sites, treatments and forest stand age (Stevenson et al, 2004; Lalor and Cookson, 2007; Peham and Bruckner, 2012). They included: L-threonine, malonic, pantothenic and quinic acids, N-acetyl glucosamine, D-cellobiose, and syringic acid. Substrates were added to soil samples at 40 % water holding capacity, and samples were incubated for 3 hours at 23˚C. The CO_2 production (micrograms CO_2 –C g^{-1} dry soil h^{-1}) was estimated by measuring pre-incubation and final UV-Vis absorbance readings at 572 nm on a Synergy HT, multidetection microplate reader (Bio-Tek Instruments, Inc.Winooski, VT, USA); absorbance values were converted to respiration rates according to Swallow and Quideau (2015).

2.2.4 Statistical analyses

The four treatments or site types analyzed were both clearcut and undisturbed stands dominated by trembling aspen (Aw undisturbed, Aw clearcut) or white spruce (Sw undisturbed, Sw clearcut). Data were analyzed in RStudio version 3.4.0 using the ‘lmPerm’ package (Wheeler & Torchiano, 2016; R Core Team, 2017). Significance was determined at $\alpha = 0.10$. A single-factor permutational analysis of variance (permANOVA) followed by Tukey’s adjustment for multiple inference (TukeyHSD) analyzed if there was an effect of site on total PLFAs (nmol g^{-1}), basal respiration (μg CO2-C g^{-1} hr^{-1}), catabolic evenness, and environmental variables (pH, total carbon and nitrogen, C/N ratio, ^{13}C, ^{15}N, tree diameter at breast height, leaf areas index, and percent ground cover of leaf litter, needles, moss, lichen, coarse woody debris, shrubs, and live vegetation). Total PLFAs were calculated as the sum of all fatty acids ranging from 14 – 24 carbon atoms, and was tallied on a nmol PLFA g^{-1} basis. Basal respiration was calculated by summing the CO_2 production rates after water addition on a μg CO_2-C g^{-1} hr^{-1} basis. Catabolic evenness (uniformity of substrate use by the microbial community) was calculated from CO_2 production rates within each substrate divided by the catabolic response of all the substrates to determine the range of functions within the microbial communities (Degens et al. 2001).

Forest floor PLFAs (mol %, after square root transformation) and MSIR response to the addition of seven substrates (μg CO2-C g^{-1} hr^{-1} after square root transformation and Wisconsin double standardization; Swallow and Quideau, 2015) among site types were analyzed with non-metric multidimensional scaling (NMDS), RStudio packages ‘vegan’ and ‘ecodist’(Goslee & Urban, 2007; Oksanen et al., 2017), followed by the multi-response permutational procedure (MRPP) with PC-Ord software version 5 (MjM Software Design, Gleneden Beach, OR.) Significance was determined at $\alpha = 0.10$. The NMDS and MRPP analyses are non-parametric distance-based techniques that do not require normal distribution of the data. The NMDS analysis grouped data points into groups of similar points in a two-dimensional space based on distances between points. The Sorenson (Bray-Curtis) dissimilarity index was used for the analysis. Environmental variables were then created as vectors to determine correlation with the NMDS solution. The strength of association between the environmental variables and points on the NMDS along the direction of the vector are indicated by two values: the R^2 value is equivalent to the correlation coefficient and is a measure of the strength of association (longer vectors have higher R^2 values); the *p* value denotes the correlations significance. Vectors with p values ≤ 0.05 were presented on the NMDS. The MRPP compares distances between groups visualized in the NMDS to determine statistical similarities or differences between the groups. The MRPP calculates three values to compare to random expectations: the T value, which represents the degree of separation between groups (larger negative values indicates greater separation); the A value describing homogeneity within groups (1 signifies homogenous groups compared to random expectation, and 0 indicates heterogeneous groups equal to what is expected by random chance); the *p* value indicates the significance of comparisons, and Bonferroni corrections were used to reduce the likelihood of making a Type I error (McCune and Grace, 2002). Characterization of site type was further analyzed by an indicator species analysis with RStudio packages ‘indicspecies’ and ‘labdsv’ (De Cacers and Legendre, 2009; Roberts, 2016). The analysis is a randomized procedure that selects individual PLFAs whose relative frequency and abundance may be used to indicate specific site types.

2.3 Results

2.3.1 Vegetation and soil characteristics

Trembling aspen was the dominant tree species regenerating in both aspen and spruce clearcuts (Table 2-1). This trend was clear in the understory as well. There were no significant differences between clearcut aspen and spruce stands in leaf area index (p=0.48), live ground cover (p=0.28), or ground cover of leaf litter (p=0.99), moss (p=1.00), or shrubs (p=0.94). Furthermore, six of the nine dominant understory species in the clearcut aspen and spruce stands were the same: fireweed (*Chamerion angustifolium* (L.) Holub), prickly rose (*Rosa acicularis* Lindl.), lowbush cranberry (*Viburnum edule* (Michx.) Raf.), palmate-leaved coltsfoot (*Petasites palmatus* (Ait.) Cronq.), twinflower (*Linnaea borealis* L.), and grasses (*Poaceae* spp.). Clearcut spruce stands were more similar to undisturbed aspen stands than undisturbed spruce stands in terms of ground cover of leaf litter (p=0.53, p<0.001, respectively), spruce needles (p=1.00, p<0.001, respectively), moss (p=0.98, p<0.001, respectively), lichen (p=1.00, p=0.21, respectively), and shrubs (p=0.99, p=0.10, respectively).

Undisturbed spruce stands had the most live ground cover (85%), dominated by a thick layer of moss (64%), a moderate amount of herbs (forbs and graminoids, 21%), and a small amount of shrubs (7%; Table 2-1). Undisturbed and clearcut spruce stands were significantly different in terms of ground cover of live vegetation (p<0.001), leaf litter (p<0.001), spruce needles (p<0.001), moss (p<0.001), and shrubs (p=0.10). Undisturbed aspen stands had less live ground cover (66%) than undisturbed spruce stands, but was dominated by double the amount of herbs (45%), and shrubs (18%). Undisturbed and clearcut aspen stands were similar in terms of ground cover of leaf litter (p=0.38), moss (p=0.99), and shrubs (p=0.82), although undisturbed aspen stands had significantly more live vegetation cover (p<0.001).

Undisturbed spruce forest floors had significantly thicker forest floors (p=0.08) and lower bulk densities (p=0.01), pH (p=0.004), total carbon (p<0.001), and total nitrogen (p<0.001) than undisturbed aspen forest floors (Table 2-2). The clearcuts of both stand types had lower nitrogen values, C/N ratios, and $\delta^{15}N$ values than their undisturbed counterparts, while $\delta^{13}C$ was the least negative in undisturbed spruce forest floors. Undisturbed and clearcut aspen forest floors had greater total carbon and pH than undisturbed and clearcut spruce forest floors (p < 2.2e-16; p=6e-04).

Clearcut aspen and spruce forest floors had similar forest floor thickness (p=0.54), bulk density (p=1.00), and $\delta^{15}N$ (p=0.99), and significantly different pH (p=0.01), $\delta^{13}C$ (p<0.001), total carbon (p=0.002), and total nitrogen (p=0.002; Table 2-2). Clearcut spruce stands were similar to undisturbed aspen stands in terms of bulk density (p=0.86), total carbon (p=0.33), total nitrogen (p=0.33), and C/N ratio (p=0.47), while clearcut and undisturbed spruce stands were similar in forest floor thickness (p=1.00), and pH (p=0.80).

2.3.2 PLFA analysis

In total, 59 PLFAs were included in the calculation of total PLFAs, which ranged from 3764 nmol g^{-1} in undisturbed aspen forest floors to 4065 nmol g^{-1} in clearcut aspen forest floors (Table 2-2). However, there were no notable differences between the four site types (p=0.58). Non-metric multidimensional scaling analysis of mol (%) PLFA data produced a 2-dimensional solution with a final stress of 13.8 (Figure 2-1). According to the MRPP analysis, the structure of PLFAs varied markedly among all site types (p < 0.0001). The smallest separations were between undisturbed and clearcut aspen forest floors (T=-3.44, A=0.07, *p*=0.03), followed by aspen and spruce clearcut (T=-4.29, A=0.08, *p*=0.01; Table 2-3). The largest separations were between undisturbed aspen and spruce forest floors (T=-10.32, A=0.38, p=0.0002), followed by aspen clearcut and spruce undisturbed (T=-9.97, A=0.33, p=0.0002). Correlation vectors of environmental factors indicated that the separation among microbial structure was driven by greater total nitrogen (R^2=0.59, p=0.001), pH (R^2=0.59, p=0.001), and leaf litter cover (R^2=0.57, p=0.002) in undisturbed and clearcut aspen forest floors, and greater $\delta^{13}C$ (R^2=0.41, p=0.003), C/N ratio (R^2=0.69, p=0.001), and moss and needle cover (R^2=0.70, p=0.002) in undisturbed spruce (Figure 2-1). In addition, the indicator species analysis detected nine PLFAs indicative of clearcut aspen forest floors, including eight saturated (i14:0, a15:0, 15:0, 17:0, 10Me17:0, 18:0, 10Me18:0, 23:0), one monounsaturated (i15:1ω6c), and one polyunsaturated (20:4ω6c), while only one saturated PLFA (14:0) was indicative of clearcut spruce forest floors. One monounsaturated (18:1ω9c) and one cyclo (cy19:0ω9c) were indicators of undisturbed aspen forest floors, while seven PLFAs including two saturated (a17:0, 20:0), four monounsaturated (15:1ω8c, 17:1ω7c, 18:1ω7c, 23:1ω4c), and one polyunsaturated (18:3ω6c) were indicators of undisturbed spruce forest floors (Table 2-4).

2.3.3 Respiration response

There were no significant differences in the MSIR response (Figure 2-2; Table 2-5) or basal respiration rates (μg CO_2-C g^{-1} hr^{-1}) between any of the site types, however undisturbed aspen forest floors had the greatest basal respiration rate overall (Table 2-2). The only significant difference in catabolic evenness was between undisturbed spruce and clearcut aspen forest floors (p=0.09), which also ordinated furthest from each other (T=-0.25; Table 2-5).

2.4 Discussion

2.4.1 Vegetation characteristics

Undisturbed spruce stands were characterized by significantly more live ground cover (85%) than undisturbed aspen (66%), however the ground cover in spruce stands was largely attributed to moss (64%), herbs (21%) and few shrubs (7%), while aspen stands were dominated by double the amount of herbs (45%) and shrubs (18%). Leaf area index, calculated during the growing season was similar between stand types (p=0.98); however greater light transmission to aspen than spruce understory has been recorded in the spring and fall when the aspen canopy is leafless (Constabel and Lieffers, 1996). Greater light transmission and higher soil nitrogen in aspen stands likely favoured shrub development, similar to results found at EMEND by Macdonald and Fenniak (2007). On the other hand, shaded conditions and less leaf litter accumulation in spruce stands provided a more favorable habitat for moss dominance (Caners et al., 2013).

Trembling aspen was the dominant tree species regenerating in both aspen and spruce clearcuts, indicating that the clearcut spruce stands are reverting to an earlier successional stage (Table 2-1). This finding is supported by Macdonald and Fenniak (2007) who found aspen to be a significant indicator of clearcut harvest in both aspen and spruce dominated forests. These data further suggest that the spruce stand prior to clearcut followed the classic successional trajectory from broadleaf- to mixed to conifer dominated forests, and that what we see now is a "legacy effect" of the aspen parent stand (Gradowski et al., 2010). The aspen bud bank from the original stand likely survived due to minimal disturbance of the forest floor during harvest because work was conducted in the winter when the ground was frozen. The growth of aspen suckers is dependent on warm soil temperatures (Kalischuk et al., 2001; Fraser et al., 2002; Landhaüsser et al., 2006), therefore clearcutting provided the proper microclimate for sucker growth and survival. Canopy cover and composition strongly influences understory communities (Berger and Puettmann, 2000; Svenning and Skov, 2002; van Oijen et al., 2005), therefore, it is not surprising that clearcut stands of both aspen and spruce had similar canopy cover (LAI p=0.48), and the same six out of nine dominant shrubs and herbaceous species within their understories. Further evidence that clearcut spruce stands are reverting to an earlier successional stage are the similarities between clearcut spruce and undisturbed aspen stands in terms of ground cover of leaf litter, moss, and shrubs. Moss was no longer able to thrive in clearcut spruce stands due to increased light transmission. These findings are supported by Caners et al. (2013) who documented the reduction of moss cover in mixedwood stands from 86% in undisturbed to 19% in 10% retention. Deciduous and coniferous species differ in leaf litter quality and quantity. Generally, the forest floor of deciduous litter has higher pH and lower C/N ratio (Man and Lieffers, 1999; Priha et al., 2001; Jerabkova et al., 2006). Higher litter quality and light transmission from the generation of aspen in the clearcut spruce stands likely promoted the growth of shrubs. This finding is supported by Macdonald and Fenniak (2007) who documented greater shrub cover, richness, and diversity in deciduous dominated forests with higher light, warmer soils, and higher nitrogen than coniferous forests.

2.4.2 Stand type differences in forest floor microbial communities

In the present study, aspen and spruce forest floors supported microbial communities with comparable total PLFAs (nmol g^{-1}) and microbial function (μg CO_2-C g^{-1} hr^{-1}), yet different microbial structure (mol % PLFA), as indicated by both the PLFA and MSIR analyses. In 2004, aspen forest floors supported greater total PLFAs than spruce forest floors. These stand-type differences were attributed to higher pH in aspen forest floors (Hannam et al., 2006). In 2016, pH was still significantly higher in aspen forest floors, yet no differences in total PLFAs were found (Table 2-2). Interestingly, total PLFAs increased significantly from 2004 to 2016 (Sw undisturbed: ~1250 to 4022 nmol g^{-1}; Aw undisturbed: ~1480 to 3764 nmol g^{-1}). It is possible that these differences in PLFA total amounts may be coming from a modification in our laboratory protocol, which is now able to quantify a wider range of PLFAs (Quideau et al., 2016).

Unlike total PLFAs, microbial structure (mol % PLFAs) varied markedly across stand types ($p < 0.0002$). There was a strong correlation between the PLFA profiles associated with the undisturbed aspen stands and forest floor pH, total carbon, total nitrogen, leaf litter cover, and catabolic evenness. Soil pH (Bååth and Anderson, 2003; Hannam et al. 2006; Freedman and Zak, 2015), total carbon and nitrogen, and litterfall (Priha et al., 2001; Grayston and Prescott, 2005) have been among the factors shown to influence microbial community structure. In our study, there was also a strong correlation between undisturbed spruce stands and forest floor C/N ratios, ^{13}C, and moss and spruce needle cover, as indicated by the vectors in the NMDS ordination (Figure 2-1). Higher C/N ratio in spruce forest floors was expected, as Hannam et al. (2006) had a ratio of 19.0 in undisturbed aspen and 25.8 in undisturbed spruce forest floors. These findings were also supported by a review conducted by Vesterdal et al. (2013), who found the largest forest floor carbon stocks under *Picea* spp. when compared to *Betula* and *Populus* spp., in 23 of 24 studied conducted in boreal and temperate regions.

2.4.3 Timber harvesting effects on forest floor microbial communities

Similar to the 2004 results, results from the current study indicated no lasting effect of clearcut harvesting on total PLFAs (nmol g^{-1}), basal respiration rates (μg CO_2-C g^{-1} hr^{-1}), or microbial function (μg CO_2-C g^{-1} hr^{-1}), across or within stand types, even though catabolic evenness varied between stand types. There are many possibilities for the absence of differences. Like 2004, samples from each site were collected only once for PLFA and MSIR analysis in June 2016, possibly masking the effects of harvesting that may have been apparent in other seasons with changes in soil temperature and moisture content (Saetre and Bååth, 2000; White et al., 2005; Hahn and Quideau, 2013; Swallow and Quideau, 2013). However, as noted by Hannam et al., 2006, other studies comparing changes in microbial communities through the seasons have discovered variation within the community, yet differences among treatments were still apparent (Grayston et al., 2001; Myers et al., 2001). Also noted by Hannam et al., 2006, the PLFA and MSIR analyses may not have been sensitive enough to distinguish changes in microbial communities. However, PLFA analysis in the present study detected differences in microbial structure across and within stand types ($p < 0.0001$). Furthermore, both MSIR and PLFA analyses have been commonly used to detect differences in microbial communities in the boreal forest (Hahn and Quideau, 2013; Swallow and Quideau, 2013; Howell and MacKenzie, 2017). Therefore, it is not likely that a single sample date or the efficacy of PLFA and MSIR analyses are the reason that harvesting effects were not discovered. On the other hand, similarities in total PLFAs, basal respiration rates, and microbial function 4.5 years to 17.5 years post-harvest can be attributed to winter harvesting. Harvesting when the ground is frozen minimizes the effects of disturbance on the forest floors, thereby allowing the microbial communities to be minimally affected.

At EMEND, harvesting effects on microbial biomass were apparent 2.5 years after clearcut on both aspen and spruce stands (Lindo and Visser, 2003). However, 4.5 years post-harvest there were no differences in microbial biomass (Hannam et al., 2006), and that was still the case in the present study 17.5 years post-harvest. Reductions in microbial biomass following clearcut are common (Bååth 1980, Bååth et al. 1995; Smith et al. 2008). Following the removal of all above-ground vegetation, Lindo and Visser (2003) reported a reduction in annual litter inputs and root biomass, both essential food sources for the soil microbial community. The microbial community is also exposed to more extreme temperatures and moisture conditions, both known to affect microbial community characteristics (Marshall, 2000; Brockett et al. 2012). Regeneration of shrub and canopy cover increased litter inputs and root biomass, and stabilized the forest floor microclimate, likely explaining why the effects of harvest on microbial biomass were no longer apparent 4.5 years post-harvest (Hannam et al., 2006).

In the present study, it was surprising that although total PLFAs, basal respiration rates, and microbial function were similar in the clearcuts and undisturbed stands, microbial community structure was significantly different, as indicated by PLFA analysis (Table 2-2, Figure 2-1) and the indicator species analysis (Table 2-4). Hannam et al. (2006) detected a greater abundance of 16:1ω5 in clearcut forest floors, and this PLFA biomarker has been reported to increase in other studies following disturbance such as clearcutting (Bååth et al., 1995; Pennanen et al., 1999) and root-severing (Siira-Pietikäinen et al., 2001). The indicator species analysis from the present study did not detect 16:1ω5 as an indicator of clearcutting in either aspen or spruce stands. On the other hand, the aspen clearcuts were characterized by high concentrations of gram-positive bacteria, including 10Me17:0, 10Me18:0, i14:0, a15:0, 17:0, and 18:0 (Table 2-4). This is in agreement with the findings from Drenosky et al. (2010), who reported increased concentrations of gram-positive PLFAs in disturbed than in wildland soils. In comparison, the undisturbed spruce stands were characterized by the presence of gram-negative bacteria (e.g.; 17:1ω7c, 18:1ω7c), which is similar to what was reported by Hannam et al. (2006).

The greatest similarity in microbial structure was seen between the undisturbed and clearcut aspen forest floors (T=-3.44). Aspen is now re-growing in the spruce clearcuts, and the three stands currently dominated by aspen (Aw undisturbed, Aw clearcut, Sw clearcut) ordinated closest together, had the greatest catabolic evenness, leaf litter cover, total nitrogen, and the lowest C/N ratio. Aspen litter typically contains more nitrogen than spruce litter (Hannam et al., 2006), which explains the lower C/N ratios. Together, these results indicate that aspen regrowth, including litterfall, roots, and root exudates, influences soil properties in the spruce clearcuts, and in turn alters the structure of the forest floor microbial community. Indeed, in the spruce clearcuts, the forest floor microbial structure ordinated closer to undisturbed (T=-5.77) and clearcut (T=-4.29) aspen than undisturbed spruce (A=-8.79) communities (Table 2-3, Figure 2-1).

2.5 Conclusions

PLFA and MSIR analyses revealed the effects of clearcut harvesting on forest floor soil microbial biomass and function were not apparent 17.5 years post-harvest. The microbial community's resilience to harvest may be the result of efforts to minimize forest floor disturbance by harvesting in the winter months when the ground is frozen, and allowing vegetation to regenerate naturally. There were differences in microbial community structure post-harvest. However, stands dominated by aspen (Aw undisturbed, Aw clearcut, Sw clearcut) were most similar structurally, and had the greatest catabolic evenness, bulk density, pH, total carbon and nitrogen, leaf litter cover, and shrub cover. Taken together, our results indicate the importance of aspen stand regeneration and its influence on soil properties and the reestablishment of microbial communities with different structure, yet similar function to communities in undisturbed soils.

Tables and Figures

Table 2-1 Main site and vegetation characteristics from spruce and aspen clearcuts and uncut controls (undisturbed). Values are means (n=9) with standard deviation in parenthesis. Bold lowercase letters (p values $\leq$ 0.1; Tukey's test) are for interpretation, according to permutational analysis of variance results.

Site type	Stand age (yr)	Dominant tree species	Dominant tree DBH (cm)	Dominant understory species	Site LAI (m^2 m^{-2})	Leaf litter ground cover (%)	Spruce needle ground cover (%)	Moss ground cover (%)	Lichen ground cover (%)	Shrub ground cover (%)	Live ground cover (%)	CWD ground cover (%)
Sw undisturbed	121, 139, 179	White spruce	29.7a (6.3)	*Cornus canadensis* *Linnaea borealis* *Poaceae spp.* *Equisetum pratense* *Chamerion angustifolium* *Rosa acicularis* *Hylocomium splendens* *Ptilium crista-castrensis*	11.6a (0.4)	12.6b (9.6)	6.1a (3.4)	63.9a (28.3)	1.7a (3.5)	6.8b (7.4)	85.1a (16.7)	1.9a (3.7)
Sw clearcut	17	Aspen	7.1b (0.9)	*Cornus canadensis* *Chamerion angustifolium* *Rosa acicularis* *Viburnum edule* *Shepherdia canadensis* *Petasites palmatus* *Poaceae spp.* *Linnaea borealis* *Rubus idaeus*	10.4a (0.7)	98.3a (5.0)	0.0b (0.0)	0.1b (0.3)	0.0a (0.0)	16.4a (7.8)	44.4c (12.2)	1.1a (2.1)
Aw undisturbed	121, 139, 179	Aspen	27.0a (4.8)	*Cornus canadensis* *Chamerion angustifolium* *Rosa acicularis* *Viburnum edule* *Poaceae spp.* *Rubus idaeus* *Fragaria virginiana* *Petasites palmatus* *Lathyrus ochroleucus*	11.8a (3.5)	92.1a (16.2)	0.0b (0.0)	2.5b (3.0)	0.0a (3.5)	17.6a (9.8)	66.1b (11.5)	2.9a (3.1)
Aw clearcut	17	Aspen	6.8b (1.0)	*Chamerion angustifolium* *Rosa acicularis* *Viburnum edule* *Poaceae spp.* *Mertensia paniculata* *Linnaea borealis* *Petasites palmatus* *Actaea rubra* *Pyrola spp.*	8.8a (4.4)	99.6a (1.3)	0.0b (0.0)	0.3b (0.8)	0.0a (0.0)	14.0ab (9.3)	32.6c (14.0)	0.9a (1.2)

Table 2-2 Main forest floor characteristics from spruce and aspen clearcuts and uncut controls (undisturbed). Values are means (n=9) with standard deviation in parenthesis.

Forest floors	Total PLFAs (nmol g^{-1})	Total respiration (μg CO_2-C g^{-1} hr^{-1})	Basal respiration (μg CO2-C g-1 hr-1)	Catabolic evenness (E)	Bulk density (g cm^{-3})	Forest floor thickness (cm)	pH	Total Carbon (mg g^{-1})	Total Nitrogen (mg g^{-1})	C:N	^{13}C	^{15}N
Sw undisturbed	4021.7a (308.7)	18508.8a (4544.2)	18508.8a (4544.2)	5.7b (0.6)	0.061b (0.01)	9.0a (1.0)	5.1b (0.4)	142.0c (15.6)	14.2c (1.6)	29.5a (4.1)	-26.6a (0.6)	0.7a (0.5)
Sw clearcut	4004.0a (627.7)	15208.5a (6802.8)	15208.5a (6802.8)	5.8ab (0.4)	0.077a (0.01)	9.0a (1.1)	5.3b (0.3)	172.0b (8.6)	17.2b (0.9)	23.2b (1.5)	-27.1b (0.4)	0.2a (0.5)
Aw undisturbed	3764.2a (535.6)	16668.4a (5309.0)	16668.4a (5309.0)	6.0ab (0.3)	0.082a (0.02)	7.3b (1.5)	5.7a (0.4)	182.8ab (9.0)	18.3ab (0.9)	21.5bc (1.7)	-27.8c (0.3)	0.6a (0.6)
Aw clearcut	4065.1a (559.3)	17041.7a (4694.7)	17041.7a (4694.7)	6.1a (0.3)	0.077a (0.01)	8.0ab (2.0)	5.7a (0.3)	197.1a (17.9)	19.7a (1.8)	19.9c (1.3)	-28.1c (0.2)	0.1a (0.6)

Table 2-3 Multi-response permutational procedure (MRPP) results for the PLFA data (mol %) of the four sampled forest floor types. The p-values are presented following Bonferroni correction.

	T	A	*p*
Overall	-13.21	0.31	< 0.0001
Forest floor x forest floor			
Aw clearcut x Sw clearcut	-4.29	0.08	0.01
Aw clearcut x Aw undisturbed	-3.44	0.07	0.03
Aw clearcut x Sw undisturbed	-9.97	0.33	0.0002
Sw clearcut x Aw undisturbed	-5.77	0.12	0.001
Sw clearcut x Sw undisturbed	-8.79	0.25	0.001
Aw undisturbed x Sw undisturbed	-10.32	0.38	0.0002

Table 2-4 Total PLFA (nmol g^{-1}) indicator species analysis.

Forest floor	PLFA	PLFA specificity*	PLFA fidelity*	Predominant origin	p-value
Sw undisturbed	18:1ω7c	1.00	0.89	Gram negative bacteria	0.001
Sw undisturbed	17:1ω7c	0.83	1.00	Gram negative bacteria	0.001
Sw undisturbed	23:1ω4c	0.57	1.00	Eukaryote	0.001
Sw undisturbed	15:1ω8c	1.00	0.33	Gram negative bacteria	0.04
Sw undisturbed	18:3ω6c	0.32	1.00	Fungi	0.001
Sw undisturbed	20:0	0.32	1.00	Nematode	0.001
Sw undisturbed	a17:0	0.27	1.00	Gram positive bacteria	0.01
Sw clearcut	14:0	0.27	1.00	Gram positive bacteria	0.002
Aw undisturbed	cy19:0ω9c	0.38	1.00	Gram negative	0.01
Aw undisturbed	18:1ω9c	0.28	1.00	Gram negative/Fungi	0.03
Aw clearcut	23:0	0.33	1.00	Eukaryote	0.001
Aw clearcut	10Me17:0	0.29	1.00	Actinomycetes	0.04
Aw clearcut	i14:0	0.29	1.00	Gram positive bacteria	0.001
Aw clearcut	i15:1ω6c	0.28	1.00	Gram negative bacteria	0.001
Aw clearcut	10Me18:0	0.28	1.00	Actinomycetes	0.01
Aw clearcut	a15:0	0.27	1.00	Gram positive bacteria	0.001
Aw clearcut	20:4ω6c	0.27	1.00	Unknown	0.02
Aw clearcut	17:0	0.27	1.00	Gram positive bacteria	0.02
Aw clearcut	18:0	0.26	1.00	Gram positive bacteria	0.03

*Specificity = 1.00: PLFA is found exclusively within one site type.

*Fidelity = 1.00: PLFA is found in all sample units within one site type.

* Gram positive bacteria (Frostegard and Bååth, 1996; Myers et al., 2001; Lores et al., 2010; Dickens et al., 2013); Gram negative bacteria (Wilkinson, 1988; Lores et al., 2010; Dickens et al., 2013); Fungi (Hannam et al., 2007); Nematode (Chen et al., 2001); Unknown (Swallow et al., 2013)

Table 2-5 Multi-response permutational procedure (MRPP) results for the MSIR response (μg CO_2-C g^{-1} hr^{-1}) of the four sampled forest floor types. The p-values are presented following Bonferroni correction.

	T	A	*p*
Overall	0.26	-0.01	0.53
Forest floor x forest floor			
Aw clearcut x Sw clearcut	0.65	-0.02	1.00
Aw clearcut x Aw undisturbed	-0.06	0.002	1.00
Aw clearcut x Sw undisturbed	-0.25	0.01	1.00
Sw clearcut x Aw undisturbed	0.15	-0.005	1.00
Sw clearcut x Sw undisturbed	0.72	-0.02	1.00
Aw undisturbed x Sw undisturbed	-0.18	0.01	1.00

Figure 2-1 NMDS ordination of PLFA (mol %) from the four sampled forest floor types. NMDS ordination produced a solution with a stress of 13.8, which was achieved after 20 iterations. Ellipses are hand drawn to reflect distinct groupings based on MRPP.

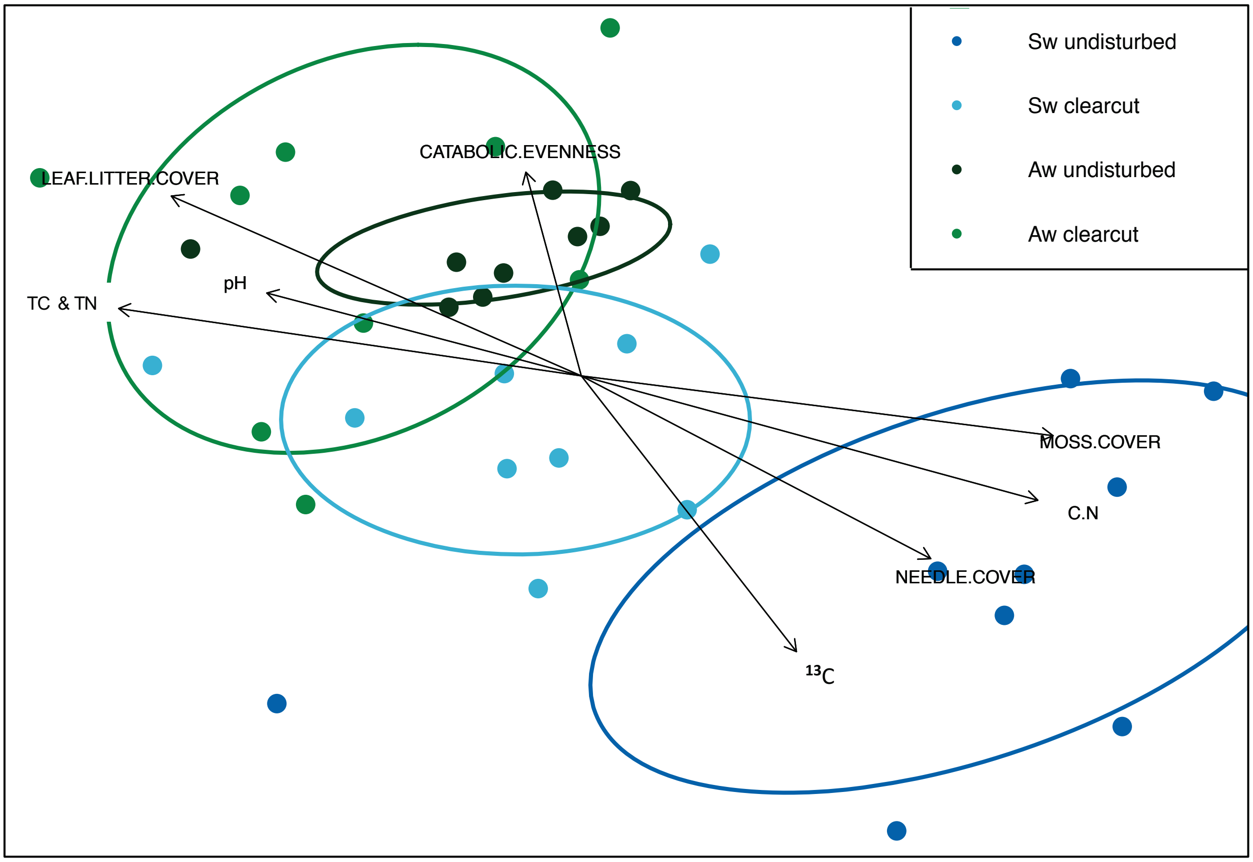
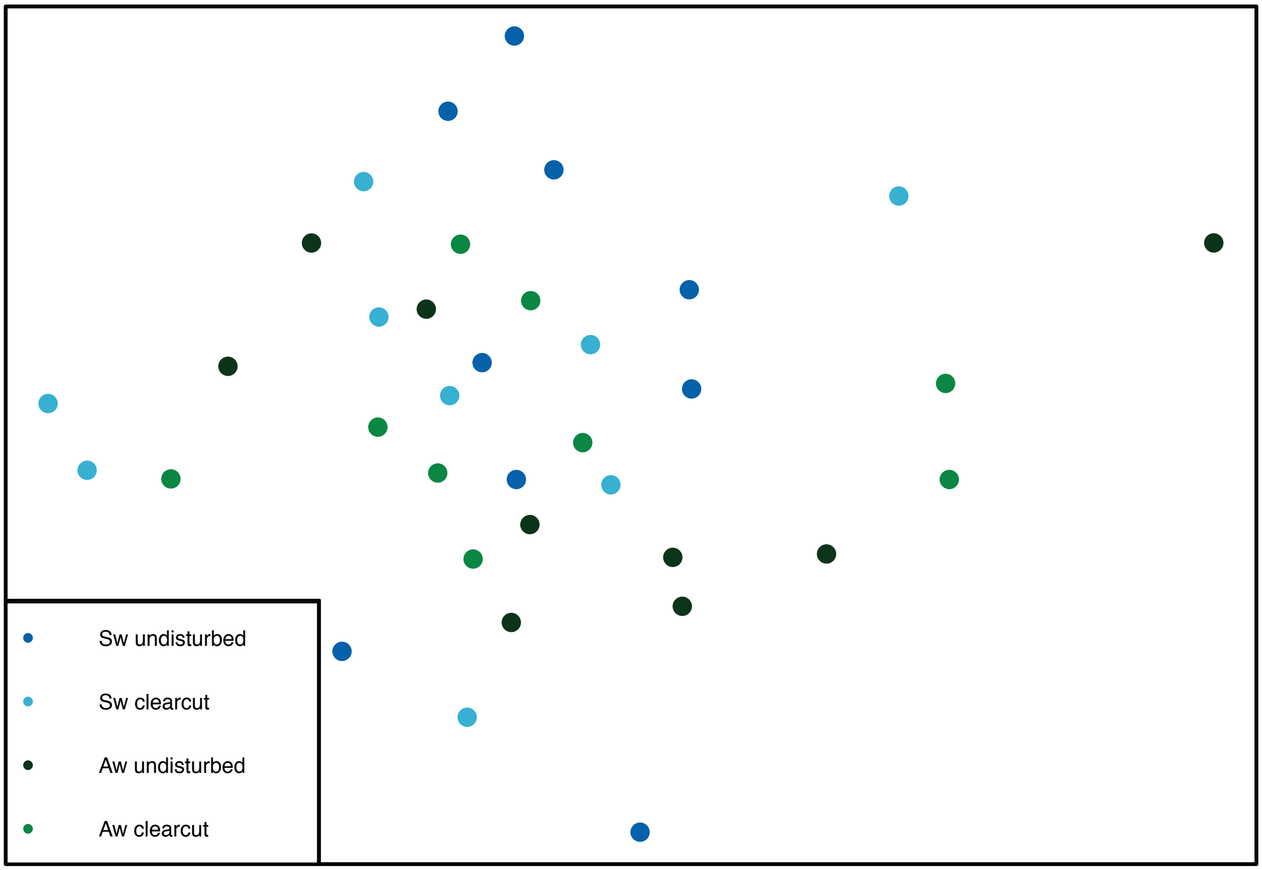


Figure 2-2 NMDS ordination of the MSIR response (μg CO2-C g^{-1} hr^{-1}) of the four sampled forest floor types. NMDS ordination produced a solution with a stress of 11.0, which was achieved after 20 iterations.



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3. CHAPTER 3 – FOREST FLOOR MICROBIAL COMMUNITIES FOLLOWING SURFACE MINING

3.1 Introduction

The boreal zone circles the northern hemisphere, covering 14% of the earth's land, and containing 33% of the earth's forests, with 552 million hectares in Canada (Natural Resources Canada, 2017). The cool temperatures and short growing season result in low litter production yet slow decomposition, allowing for the accumulation of large carbon stocks in boreal forest floors (Foster and Bhatti, 2006). The forest floor and mineral soil organic matter account for approximately 65% of boreal total ecosystem carbon (Kurz et al., 2013). The forest floor is also essential to boreal ecosystem function. It is a repository of essential plant nutrients (Fuqiang et al., 2010; Macdonald et al., 2010), stores and purifies water (Prescott et al., 2000; Binkley and Fisher, 2013), provides energy for biogeochemical reactions (Bashkin, 2003; Swallow and Quideau, 2013), and is the site of microbial activity and nutrient cycling (Aerts, 1997; Foster and Bhatti, 2006; Royer-Tardif et al., 2010).

Canada's boreal zone is plentiful in resources and essential to the country's economy in part due to the oil and gas sectors in the west (Bogdanski 2008; Brandt et al., 2013). Alberta's oil sand reserves are the second largest in the world and are estimated to hold up to 1.7 trillion barrels of bitumen. Approximately 20 % of the reserves are close enough to the surface to be recovered by surface mining, and span 4800 km^2. Surface mining involves deforestation, and excavation of native soils and underlying geological deposits (Fung and Macyk, 2000; GoA, 2009). Excavation results in severed biogeochemical processes between the vegetation, soil, and groundwater. The development of forest floors in landscapes being reclaimed to upland forests is essential to the restoration of those ecosystem processes. The benefits of vegetation re-establishment in promoting soil biological communities and biogeochemical cycling within post-mining landscapes have been recorded globally. Increasing plant cover and litter inputs have been found to positively correlate with soil biota densities in post-mining chronosequences from Eastern Europe (Pizl, 2001; Frouz et al., 2001, 2008). In England, Bentham et al. (1992) compared undisturbed woodlands to restored woodlands following opencast coal mining, and attributed the active microbial biomass in 8-year restored woodlands to the continuous grass cover. In the jarrah forest of Australia, soil microbial biomass appeared to be directly driven by vegetation productivity and litter inputs to the soil (Jasper, 2007). Similarly, in eastern US soils following coal mining, microbial biomass was higher in older (> 20 years) reclaimed sites under forest vegetation than in younger reclaimed sites under grass vegetation (Clayton et al., 2009). In turn, reestablishment of soil biological communities has been linked to the successful reestablishment of late successional plant species (De Deyn et al., 2003) and the importance of feedback mechanisms between above-ground and below-ground biomass has been acknowledged in restoration ecology (Kardol and Wardle, 2010).

Reconstruction of post-mining landscapes in the AOSR began in the 1980s. Past studies have shown that microbial communities in these reclaimed landscapes remain different from the target upland forests (Dimitriu et al., 2010; Sorenson et al., 2011; Hahn and Quideau, 2013). However, those studies sampled soils by depth, and samples contained a mixture of the organic coversoil used during soil reconstruction and of the forest floor that had started to develop at the reclaimed sites following reforestation. For the present study, the forest floor developing on reclaimed sites was sampled separately to compare it more directly to native forest floors of the surrounding areas. This sampling strategy allowed us to isolate the direct influence of the developing forest floors on the structural and functional diversity of soil microbial communities. The overall objective of this research was to determine how the structural and functional diversity of microbial communities may develop in reclaimed AOSR soils. This was accomplished by assessing microbial communities in a chronosequence of sites reclaimed 8-31 years ago, planted to either trembling aspen (*Populus tremuloides* Michx.) or white spruce (*Picea glauca* (Moench) Voss.), and comparing them to their mature natural counterparts of the region. We hypothesized that microbial communities in the forest floor of reclaimed sites would be more similar to those found in natural forested stands, as compared to the communities in the forest floor combined with underlying peat-mineral mix. Additionally, we assessed the importance of tree litter quality on microbial recovery by comparing reclaimed stand types dominated by either trembling aspen or white spruce. Here, we hypothesized that microbial recovery would proceed at a faster rate under aspen stands as compared to spruce stands due to faster tree growth and increased litterfall.

3.2 Materials and Methods

3.2.1 Study area and site selection

The study area is located approximately 35 km north of Fort McMurray, Alberta, Canada (56° 43' 34" N, 111° 22' 49" W), in the Wabasca Lowland Ecoregion of the Boreal Plains Ecozone of western Canada (Wiken, 1986; Ecoregions Working Group, 1989). The climate is characterized by long cold winters and cool short summers. The mean monthly air temperature ranges from -17˚C in January to 17˚C in July. The mean annual precipitation is 419 mm with rainfall accounting for 316 mm predominantly during the growing season (Environment Canada, 2015).

Prior to disturbance by mining, the study area was for a large part comprised of lowland ecosystems dominated by black spruce (*Picea mariana* (Mill.) BSP) and tamarack (*Larix* *laricina* (Du Roi) K. Koch). However, reclamation is converting some of the lowland areas to upland forests dominated by trembling aspen and white spruce (Fung and Macyk, 2000; MacKenzie and Quideau, 2010). Soils in the area have developed on till, fluvial and lacustrine parent geological materials deposited during the Wisconsin glaciation 70,000 to 10,000 years ago (Crown and Twardy, 1970). Histosols (Organic soils) and Gleysolic soils are found in lowlands, while Dystric Cambisols (Brunisols) and Albic (Gray) Luvisols are found upland (Soil Classification Working Group, 1998; IUSS Working Group WRB, 2014).

Twenty study sites were chosen in the AOSR within a 13 by 15 km area to minimize climatic variations so that the effects of vegetation and time since reclamation could be isolated (Table 3-1). As much as possible, level sites were chosen. Soils at all reclaimed sites had been capped with 20 cm of a mixture of peat and mineral substrate (PMM), serving as a coversoil to promote vegetation growth. While the mineral substrate underlying the PMM cap varied in origin, its texture was comparable at all sites selected. The 15 reclaimed sites on the Syncrude and Suncor mining leases were further selected to form a chronosequence of years since reclamation, including three young reclaimed replicates less than 15 years old (planted to aspen and spruce). Five sites planted to aspen included three mid reclaimed replicates (17-27 years) and two old reclaimed replicates (> 30 years). Seven sites planted to spruce consisted of four mid reclaimed replicates (23-25 years) and three old reclaimed replicates (> 30 years). In addition, five mature undisturbed sites (three aspen and two spruce, > 30 years old) were chosen to allow for comparison of microbial processes between reclaimed and undisturbed soils.

3.2.2 Vegetation survey and soil collection

The twenty study sites were described and sampled in July 2015. At each site a centre point was selected and four sampling locations identified 10 m from the centre point in the four cardinal directions to create a 400 m^2 plot. Several vegetation characteristics were described within a 1 m^2 area around each of the four sampling locations; these included: leaf area index (LAI); dominant tree, shrub and forb species; and ground cover (%) of lichen, moss, leaf litter, spruce needles, coarse woody debris and shrubs (Royer and Dickinson, 2007). LAI was described as defined by Marshall and Waring (1986) as the total surface area of leaves per unit of ground area, and was measured with a Licor 2200 30 cm from the ground. Within the 400 m^2 plots, measurements included: number of dominant trees, and dominant tree diameter at breast height (DBH) or at 10 cm from the soil surface, if shorter than 1.3 m. Average tree age was determined at natural sites by analyzing the rings of cores taken with an increment borer from three trees with the largest DBH.

The top 7.5 cm of soil was sampled at each sampling location using a 7.5 cm diameter metal core. At the natural sites (Table 3-1), samples consisted of forest floor only, and were named "Nat.FF". On young reclaimed sites, samples consisted of peat material (PMM) overlain by a nascent forest floor and were named FF.PMM-Yg. At the mid and old reclaimed sites, sampling was further adjusted based on the thickness of forest floor that had accumulated. As this forest floor is developing as part of a novel ecosystem following the definition of Hobbs et al. (2009), we chose to refer to it as the "novel" forest floor. On reclaimed sites with < 2 cm forest floors, the top 7.5 cm of combined novel forest floor and PMM was sampled together (FF.PMM-MidandOld). On reclaimed sites with forest floor thicknesses > 2 cm, two soil layers were sampled separately, including the novel forest floor (Novel.FF), which was sampled in its entirety, and the underlying peat material (PMM). The four sampling locations were homogenized to create one or two soil samples representative of each site (one sample for sites with < 2 cm, or > 7.5 cm forest floors, and two samples for the rest of the reclaimed sites).

Samples for phospholipid fatty acid (PLFA) and multiple substrate induced respiration (MSIR) characterization were kept cool on ice during transport, and stored at -20˚C within 12 hours. Upon return to the laboratory PLFA samples were stored at -86˚C, then freeze dried prior to extraction.

3.2.3 Laboratory analyses

Gravimetric water content and bulk densities were determined by oven drying soil samples at 65˚C for 48 hours and weighing the samples before and after drying. The pH was measured by adding 0.01 M calcium chloride to air-dried soil samples using a 1:4 soil:solution dilution ratio (Kalra and Maynard, 1991). For total carbon and nitrogen determination, samples were air dried, sieved through a 2 mm screen, ground with a Retsch MM200 ball mill grinder, then analyzed by flash combustion on a Costech Model EA 4010 Elemental Analyzer (Costech International Strumatzione, Florence, Italy, 2003). For stable isotope ^{13}C and ^{15}N determination, samples were air dried, sieved, and ground as described above, then analyzed by flash combustion on a ThermoFinnigan Delta Advantage Continuous Flow Isotope Ratio Mass Spectrometer (Thermo Finnigan Corp, Bremen, Germany, 2003).

The structural composition of soil microbial communities and total microbial biomass were estimated using PLFA analysis. Polar lipids were extracted from 0.7 g freeze dried soil using a modified Bligh and Dyer extraction as described in Hannam et al. (2006). Polar lipids were purified on pre-packed silicic acid columns (Agilent Technologies, Wilmington, DE, USA). They were treated to mild alkaline methanolysis to form fatty acid methyl esters (FAMEs), which were quantified using an Agilent 6890 Series capillary gas chromatograph (Agilent Technologies, Wilmington, DE, USA). Fatty acid peaks were identified using MIDI peak identification software (MIDI, Inc., Newark, DE) and designated with the X:YωZ nomenclature where X shows the number of carbon atoms, Y, the number of double bond, and Z, the ordination of the first double bond from the aliphatic (ω) end of the molecule.

Functional diversity of the soil microbial communities was characterized with multiple substrate induced respiration (MSIR), which measures the catabolic response of the community to a range of substrates (Peham and Bruckner, 2012). The MSIR method from Degens and Harris (1997) was modified to use a whole-soil approach as described by Swallow and Quideau (2015). The seven substrates used, which are naturally found in soils and root exudates, were chosen for their ability to discriminate between different sites, treatments and forest stand age (Stevenson et al, 2004; Lalor and Cookson, 2007; Peham and Bruckner, 2012). They included: L-threonine, malonic, pantothenic and quinic acids, N-acetyl glucosamine, D-cellobiose, and syringic acid. Substrates were added to soil samples at 40 % water holding capacity, and samples were incubated at 23˚C for 1.5 hours. The amount of CO_2 produced (micrograms CO_2 –C g^{-1} dry soil h^{-1}) was estimated by colorimetric detection at 572 nm according to Swallow and Quideau (2015).

3.2.4 Statistical analyses

For statistical analyses, samples or measurements collected at the four sampling locations of each site were combined, totaled and expressed as site averages. These site values were used for all data analyses and analyzed in RStudio version 3.4.0 (R Core Team, 2017). Values were tested for differences between the seven canopy type and stand age categories (Yg., Mid.Aw, Mid.Sw, Old.Aw, Old.Sw, Nat.Aw, Nat.Sw), and among the five sampled soil layers (Nat.FF, FF.PMM-Yg, FF.PMM- MidandOld, PMM, Novel.FF). At sites where a novel forest floor was sampled separately from the underlying peat material, data were standardized when comparing among canopy types and stand ages using the relative proportion (thickness) of each horizon and its corresponding bulk density. Significance was determined at $\alpha = 0.10$.

A single-factor permutational analysis of variance (permANOVA) followed by Tukey's adjustment for multiple inference (TukeyHSD) using the RStudio 'lmPerm' package, analyzed if there was an effect of canopy type, stand age, and soil layer on microbial total PLFAs and total respiration (Wheeler & Torchiano, 2016). Total PLFAs was calculated as the sum of all fatty acids ranging from 14 – 20 carbon atoms, and was tallied on a nmol PLFA g^{-1} basis. Total respiration was calculated by summing the total CO_2 production rates for each of the seven substrates in addition to water on a μg CO_2-C g^{-1} hr^{-1} basis.

The PLFA data were analyzed using non-metric multidimensional scaling (NMDS) with RStudio packages 'vegan' and 'ecodist' (Goslee & Urban, 2007; Oksanen et al., 2017), followed by the multi-response permutational procedure (MRPP) with PC-Ord software version 5 (MjM Software Design, Gleneden Beach, OR.) NMDS and MRPP analyses are non-parametric distance-based techniques that do not require the data to be normally distributed. The NMDS analysis grouped data points into classes of similar points in a two-dimensional space based on distances between points. The MRPP calculates three values to compare to random expectations: the T value, which represents the degree of separation between groups, larger negative values indicating a greater separation between groups; the A value describing homogeneity within groups, where 1 signifies homogenous groups compared to random expectation, and 0 indicates heterogeneous groups equal to what is expected by random chance; the p value indicates the significance of comparisons (McCune and Grace, 2002). The PLFA data were expressed on a mol % basis and square root transformed prior to conducting the NMDS and MRPP. The Sorenson (Bray-Curtis) dissimilarity index was used for the NMDS analysis. Catabolic evenness (uniformity of substrate use by the microbial community) was calculated from CO_2 production rates within each substrate divided by the catabolic response of all the substrates to determine the range of functions within the microbial communities (Degens et al. 2001).

A single-factor permutational analysis of variance (permANOVA) followed by Tukey's adjustment for multiple inference (TukeyHSD) using the RStudio 'lmPerm' package, analyzed if there was an effect of environmental variables (pH, moisture content, total carbon, C/N, ^{13}C, ^{15}N) on soil layer. Environmental variables were then created as vectors to determine correlation with the PLFA NMDS solution. The strength of association between the environmental variables and points on the NMDS along the direction of the vector are indicated by two values: the R^2 value is equivalent to the correlation coefficient and is a measure of the strength of association (longer vectors have higher R^2 values); the p value denotes the correlations significance. Vectors with p values ≤ 0.1 were presented on the NMDS. Soil layer characterization was further analyzed by an indicator species analysis with RStudio packages 'indicspecies' and 'labdsv' (De Cacers and Legendre, 2009; Roberts, 2016). The analysis is a randomized procedure that combines the relative abundance and relative frequency of PLFAs within the soil layers.

3.3 Results

3.3.1 Vegetation and soil characteristics

The number of dominant trees present ranged from 275 to 900/ha at the natural sites, and 375 to 2175/ha at the reclaimed sites (Table 3-1). Leaf area index increased from the young reclaimed (0.4 m^2 m^{-2}) to the old reclaimed sites (3.5 m^2 m^{-2}). Similarly, DBH increased from young reclaimed to natural sites (aspen p=0.20, spruce p=0.04). Understory on young reclaimed sites was largely comprised of grasses (*Poaceae* spp.). Mid reclaimed aspen understory included early successional species such as grasses, dandelion (*Taraxacum officinale* L.), and fireweed

(*Chamerion angustifolium* L. Holub). Old reclaimed aspen stands contained grass, moss, alsike clover (*Trifolium hybridum* L.), and wild strawberry (*Fragaria virginiana* Duchesne). The forest floor of mid and old reclaimed spruce stands was largely comprised of a spruce needle litter layer with few early successional understory species and biocrusts of ribbed bog moss (*Aulocomnium palustre* Hedw.), big red stem *(Pleurozium schreberi* Michx.), and long-necked bryum (Leptobryum pyriforme). Natural aspen stands included bunchberry *(Cornus Canadensis* L.), twinflower (*Linnaea borealis* L.), and prickly rose (*Rosa acicularis* Lindl.). Natural spruce stands also included bunchberry, twinflower, and prickly rose, in addition to bishop's cap (*Mitella nuda* L.), palmate-leaved coltsfoot (*Petasites palmatus* Ait.) and meadow horsetail (*Equisetum pratense* Ehrhart).

The pH values of the five sampled soil layers ranged from 6.0 to 6.8, and their C/N ratios ranged from 18.6 to 20.6, both presenting little variation among layers (Table 3-2). On the other hand, total carbon concentrations and moisture contents increased appreciably from the young and mid-reclaimed sites where the forest floor and underlying peat materials were sampled together to the novel forest floor (Novel. FF) where levels became comparable to the natural forest floor (Nat.FF). At the older sites where the novel forest floor was sampled separately, the underlying peat material (PMM) had total carbon concentrations and moisture contents comparable to the mixed materials of the younger sites. There was little variation among soil layers in $\delta^{13}C$ values, ranging from -26.1 to -28.0 ‰ (Table 3-2). The greatest variation in $\delta^{15}N$ values was between reclaimed forest floor (-1.3 ‰) and peat material (1.6 ‰).

3.3.2 PLFA analysis

Total PLFAs (nmol g^{-1}) were initially analyzed by canopy type and stand age, but no significant differences were detected among sites (p=0.34; Figure 3-1). On the other hand, analysis by soil layers showed that total PLFAs increased significantly from the peat-mineral mix (833 nmol g^{-1}) to the novel forest floor (1664 nmol g^{-1}) where levels became comparable to the natural forest floor (Figure 3-2).

Non-metric multidimensional scaling analysis of mol (%) PLFA data produced a 2-dimensional solution with a final stress of 22.3 (Figure 3-3). The MRPP analysis (Table 3-3) of data grouped by soil layer indicated that soil microbial structure varied markedly among many of the soil layers ($p<0.001$). The novel forest floor was significantly different from all of the other soil materials, including the natural forest floor. Interestingly, samples from the novel forest floor layer clustered together, while the underlying peat samples that had been sampled at the same sites were much more widely spread. These peat samples were also significantly different from the natural forest floor samples. Correlation vectors of environmental factors indicated that the separation among soil layers was driven by greater total carbon ($R^2=0.27$, $p=0.03$) and moisture contents ($R^2=0.22$, $p=0.05$) in natural and reclaimed forest floors, and higher $\delta^{15}N$ values ($R^2=0.38$, $p=0.005$) in the peat-mineral mix sampled alone or combined with the nascent forest floor (Table 3-2). In addition, the indicator species analysis detected six PLFAs that were indicators of young reclaimed sites, including five saturated PLFAs (i15:0, i17:0, 10Me16:0, 10Me18:0, 20:0), and one monounsaturated PLFA (16:1ω5c). One saturated PLFA (a17:0) was an indicator of old reclaimed spruce forest floors, and three monounsaturated PLFAs (16:1ω7c, a17:1ω9c, 18:1ω7c) were indicators of natural spruce forest floors (Table 3-4).

3.3.3 Respiration response

Total respiration was initially analyzed by canopy type and stand age, and significantly increased from young to old reclaimed sites where levels became comparable to natural forest floor in both aspen ($p=0.69$) and spruce ($p=0.26$) stands (Figure 3-4). Total respiration and catabolic evenness were further analyzed by soil layer. While catabolic evenness did not vary markedly across soil layers, total respiration (μg CO_2-C g^{-1} hr^{-1}) increased significantly from the young reclaimed sites to the older sites where the reclaimed forest floors were sampled separately and where levels became comparable to natural forest floor (Table 3-2). The greatest total respiration was found in reclaimed forest floors while levels in natural forest floor and mid-old reclaimed forest floor combined with peat-mineral mix were comparable. Microbial communities in reclaimed forest floors had the greatest respiration response for the majority of substrates administered during MSIR (Figure 3-5). However, the response for natural forest floor significantly exceeded reclaimed forest floor for syringic acid. In all cases, the two forest floors respired significantly more than the materials containing peat.

3.4 Discussion

3.4.1 Effects of time since reclamation and canopy type

Total soil PLFAs (nmol g^{-1}) did not show any clear relationship with time since reclamation (Figure 3-1). These findings are supported by Martin (2016) who found no significant differences in total PLFAs between natural (71-131 years) and reclaimed (4-27 years) sites in the AOSR. In contrast, studies conducted by Dimitriu et al. (2010) and Hahn and Quideau (2013) report an increase in total PLFAs with time since reclamation. It is likely that study design contributed to the incongruity between results. Similar, to our study, Martin (2016) compared natural sites to reclaimed sites capped with a peat-mineral coversoil. Dimitriu et al. (2010) also considered the peat-mineral coversoil, yet made comparisons between natural sites and those reclaimed with ten different reclamation prescriptions, and found that total PLFAs peaked at 19-27 years post reclamation. Hahn and Quideau's (2013) study was similarly designed in terms of reclamation prescription, however reclaimed sites ranged in age from 1-7 years with total PLFAs reaching 354 nmol g^{-1} after seven years, whereas our reclaimed sites ranged in age from 8-31 years, with total PLFAs reaching the higher values (850 nmol g^{-1}) after eight years. It is possible that total PLFAs have recovered eight years post-reclamation on sites capped with a peat-mineral coversoil. In other parts of the world, including Europe, the US, and Australia, soil microbial carbon has been shown to respond quite rapidly to vegetation regrowth during land reclamation (e.g.; Jefferies et al., 1981; Corbett et al., 1996; Jasper, 2007). Soil microbial biomass has been proposed as an early indicator of soil quality improvement, and microbial biomass may increase in parallel to increases in carbon content as soils recover following disturbance (Powlson et al., 1987; Jasper, 2007). The situation may be different in the AOSR where disturbance does not necessarily result in a decrease in soil carbon but where instead total carbon stocks in reconstructed soils are typically higher than those in the surrounding undisturbed upland forest (Anderson, 2014).

Contrary to our initial hypothesis, the effects of stand type were also not apparent for total soil PLFAs. This was unexpected as aspen forest floors often have higher total PLFAs (Hannam et al., 2006) due to better litter quality when compared to coniferous litter (Flanagan and Van Cleve, 1983; Lindo and Visser, 2003). It is possible that the influence of tree species was confounded by other site factors such as pH and the absence of an H layer in reclaimed stands (Prescott and Vesterdal, 2013). Prescott and Grayston (2013) compared tree species and found the most pronounced differences in microbial communities within the F layer, while our reclaimed forest floors often lacked an F layer and the H layer was absent in all cases. Similarly, Hannam et al. (2006) measured higher total PLFAs in aspen than spruce forest floors that they attributed in part to a higher pH in the aspen stands; in contrast, in the current AOSR study, aspen forest floors had a lower pH (5.6) than spruce forest floors (6.6).

As opposed to total PLFAs, total respiration (μg CO_2-C g^{-1} hr^{-1}) showed a clear evolution with time since reclamation, and increased from the younger (8-11 years) to the older (17-31 years) reclaimed stands (Figure 3-4). Soil respiration is an important attribute of soil quality, and has been proposed as an index of overall microbial activity to assess restoration success in degraded lands (Harris, 2003). Our results indicate that while the size of the microbial communities (as indicated by total PLFAs) did not follow any clear pattern with time since reclamation, the activity of the microbial communities present at the reclaimed sites increased with time, and reached levels comparable to natural forest soils after 30 years (Figure 3-4).

3.4.2 Influence of the soil layers

The forest floor materials, regardless of whether they were sampled from the reclaimed sites or the natural forests exhibited higher total PLFAs and higher respiration response to substrate addition than the peat-based materials (Figures 3-2 and 3-5). Interestingly, the forest floors also contained higher carbon concentrations than the peat materials. When results were normalized based on each material's organic carbon content, total respiration rates were similar in the forest floor materials and in the mid-old reclaimed forest floor combined with the underlying peat-mineral mix (124-5 mg CO_2-C g of C^{-1} hr^{-1}). In comparison, the peat material overlain by a nascent forest floor (PMM-Yg) and the peat material sampled alone (PMM) had lower respiration rates ranging from 80 to 104 mg CO_2-C g of C^{-1} hr^{-1}. These results indicate that while the higher carbon concentrations in the forest floors partially explain their higher respiration rates, their chemical composition is also an important factor, since their respiration rates remained higher than the peat when normalized on a carbon basis. Similarly, to total PLFAs and total respiration, the structural composition of the forest microbial communities was statistically different from that of the peat materials (Table 3-3). Soil water content and carbon availability are two major controls of microbial structural composition (Drenosky et al. 2010), and this appeared to be the case in our study where both moisture and carbon contents were statistically higher in the forest floors (Table 3-2), and were correlated to the PLFA pattern in ordination space (Figure 3-3). In addition, the structural composition of the peat material sampled alone (PMM) was much more widely spread in ordination space than the novel forest floor that had developed atop the PMM (Table 3-3, Figure 3-3). The variance in microbial community structure within the peat mineral coversoil was not surprising, as the composition of the coversoil was also highly variable across reclaimed sites. Some sites had a homogenous mixture of peat and mineral soil, while some had a higher percentage of peat, and others had a higher percentage of mineral soil. Furthermore, the origin of the peat mineral coversoil is unknown. It is possible that the sites in our study were reclaimed with peat and mineral soil salvaged from different wetlands, which would likely vary in microbial structural composition.

While the overall structural composition of the microbial communities did not show any differences between aspen and spruce forest floors, further statistical analysis identified three indicator PLFAs that were specific to the spruce forest floors (Table 3-4); these three PLFAs can be attributed to gram-negative bacteria (Zelles, 1997; Zog et al., 1997; Kaur et al., 2005). Similarly to our study, Dimitriu et al. (2010) reported that mono-unsaturated PLFAs were more abundant in natural forest floors than in reclaimed soils. Norris et al. (2013) contrasted the incorporation of ^{13}C-glucose into AOSR soils under aspen and spruce vegetation, and found that incorporation into 18:1ω7c (one of the indicator PLFA of spruce forest floors in our study, Table 3-4) was higher under spruce than under aspen. Hannam et al. (2006), who worked in mixedwood forests of central Alberta, also commented on the strong influence that spruce vegetation may have on the PLFA profile of forest floors, as five of the six PLFAs that she reported with high indicator values were found exclusively in spruce or mixed stands containing spruce. In contrast to the spruce forest floors, the majority of indicator PLFAs identified at the reclaimed sites were saturated PLFAs, and typically occur in greater concentrations in gram-positive bacteria (Zelles, 1997; Myers et al., 2001). One exception was the 16:1ω5c PLFA that was detected as an indicator species of the young reclaimed sites (Table 3-4). This PLFA has been used as an indicator of both gram-negative bacteria and arbuscular mycorrhizal fungi (Zogg et al., 1997; Olsson, 1999), and is often found in higher concentrations in forest soils following clearcutting that are often invaded by grasses (Hannam et al., 2006). Thus, in our study, it is not surprising that 16:1ω5c was found to be an indicator PLFA for the young reclaimed sites, where the understory was largely comprised of grasses (Table 3-1). Lastly, the dominance of gram-positive PLFA indicators for the reclaimed soils is in agreement with Drenosky et al. (2010), who reported increased concentrations of gram-positive PLFAs in disturbed than in wildland soils.

3.5 Conclusions

PLFA and MSIR analyses revealed that soil microbial structure and function within the reclaimed sites were dependent on the development of a forest floor regardless of the dominant tree species present. When comparing samples comprised strictly of forest floor to those containing peat, peat had the lowest total PLFAs (nmol g^{-1}), respiration and respiration response (μg CO_2-C g^{-1} hr^{-1}), carbon, and moisture contents, and a significantly different microbial community structure. Total PLFAs, total respiration and respiration response to the majority of substrates, pH, moisture content, total carbon, and C/N ratio were comparable within the forest floors developed at either the natural or reclaimed sites. However, microbial community structure was still significantly different. Taken together, our results document the importance of forest floor development atop the peat-mineral coversoil in terms of reestablishing a microbial community with different structure, yet similar function to that present in undisturbed soils.

Tables and Figures

Table 3-1 Main characteristics of the 20 study sites.

Location (˚N, ˚W)	Site	Stand age (yr)	Dominant tree species	Number of dominant trees/ha	Dominant tree DBH (cm)	Dominant understory species	Site LAI (m^2 m^{-2})	Reclamation prescription or natural soil	Forest floor thickness (cm)
56.99871, -111.61543	Young reclaimed	11	White spruce	400	6.3	*Poaceae* spp. *Epilobium angustifolium* *Rubus idaeus*	1.4	PMM/Subsoil	2.0 (0.8)
57.01005, -111.72236	Young reclaimed	8	Aspen	800	2.0	*Fragaria virginiana* *Arctostapylos uva-ursi* *Vicia* spp.	0.3	PMM/Subsoil	1.8 (0.5)
57.01000, -111.72236	Young reclaimed	8	Aspen	525	1.3	*Equisetum pratense* *Poaceae* spp. *Vicia americana*	0.3	PMM/Subsoil	1.8 (0.3)
57.00123, -111.60873	Mid reclaimed	24	Aspen	925	5.7	*Taraxacum officinale* *Epilobium angustifolium* *Rubus pubescens*	2.6	PMM/Subsoil	3.6 (1.9)
56.99556, -111.61914	Mid reclaimed	17	Aspen	525	4.0	*Taraxacum officinale* *Achillea millefolium* *Trifolium hybridum*	2.7	PMM/Subsoil	1.9 (1.1)
57.08326, -111.61208	Mid reclaimed	27	Aspen	2175	6.0	*Poaceae* spp. *Taraxacum officinale* *Rubus idaeus*	1.9	PMM/Subsoil	3.2 (0.6)
56.99253, -111.56313	Mid reclaimed	25	White spruce	400	15.7	*Aster ciliolatus* Moss spp. *Pyrola minor*	6.4	PMM/LOS	4.5 (0.7)
56.99092, -111.53693	Mid reclaimed	24	White spruce	1650	5.4	*Aulocomnium palustre* *Rubus idaeus* *Medicago sativa*	1.9	PMM/OB	1.3 (0.9)
56.99222, -111.53276	Mid reclaimed	23	White spruce	1050	7.6	*Pleurozium schreberi* *Fragaria virginiana* *Taraxacum officinale*	2.3	PMM/OB	0.9 (0.5)

Table 3-1 continued.

Location (˚N, ˚W)	Site	Stand age (yr)	Dominant tree species	Number of dominant trees/ha	Dominant tree DBH (cm)	Dominant understory species	Site LAI (m^2 m^{-2})	Reclamation prescription or natural soil	Forest floor thickness (cm)
56.99769, -111.53362	Mid reclaimed	24	White spruce	1600	8.6	*Pleurozium schreberi* *Leptobryum pyriforme* *Taraxacum officinale*	5.1	PMM/OB	1.9 (0.3)
56.99108, -111.56409	Old reclaimed	31	Aspen	375	12.2	*Pyrola asarifolia* *Fragaria virginiana* *Calamagrostis canadensis*	3.3	PMM/Subsoil	4.0 (0.7)
56.99837, -111.54800	Old reclaimed	30	Aspen	1775	4.0	*Festuca* spp. *Pleurozium schreberi* *Trifolium hybridum*	2.4	PMM/OB	2.3 (1.0)
56.99326, -111.57085	Old reclaimed	30	White spruce	1450	12.2	*Pleurozium schreberi* *Aquilegia brevistyla* *Aster ciliolatus*	6.2	PMM/OB	3.4 (2.1)
57.02367, -111.49973	Old reclaimed	31	White spruce	675	13.2	Fern spp. *Fragaria virginiana* Moss spp.	2.9	PMM/OB	4.6 (3.6)
56.99865, -111.54722	Old reclaimed	31	White spruce	850	11.6	Moss spp. Peltigera spp. *Pyrola asarifolia*	ND	PMM/OB	1.5 (0.4)
56.96378, -111.72173	Natural	54	Aspen	900	9.6	*Cornus canadensis* *Linnaea borealis* *Rosa acicularis*	3.4	Gleyed Gray Luvisol	8.8 (2.2)
56.95859, -111.72289	Natural	60	Aspen	950	9.7	*Cornus canadensis* *Petasites palmatus* *Linnaea borealis*	1.9	Gleyed Gray Luvisol	8.8 (1.9)
57.25674, -111.62381	Natural	42	Aspen	650	11.0	*Cornus canadensis* *Linnaea borealis* *Rosa acicularis*	3.8	Orthic Dystric Brunisol	11.8 (1.7)

Table 3-1 continued.

Location (˚N, ˚W)	Site	Stand age (yr)	Dominant tree species	Number of dominant trees/ha	Dominant tree DBH (cm)	Dominant understory species	Site LAI (m^2 m^{-2})	Reclamation prescription or natural soil	Forest floor thickness (cm)
56.94395, -111.73924	Natural	35	White spruce	575	10.6	*Petasites palmatus* *Rosa acicularis* *Cornus canadensis*	3.7	Gleyed Gray Luvisol	17.3 (2.6)
57.26284, -111.63018	Natural	103	White spruce	275	17.3	*Mitella nuda* *Rosa acicularis* *Equisetum pratense*	3.8	Orthic Gray Luvisol	15 (6.5)

*Description of reclamation prescriptions are from Turcotte et al. (2009). PMM: peat mineral mix: 25-50% (vol/vol) peat + mineral soil mixture that was stockpiled prior to application; Subsoil: mineral soil salvaged to a depth of 3 m; OB: overburden: geological substrate removed to access oil sands deposits; LOS: lean oil sand: sand with <10% oil. Stand age natural sites: average age of the 3 largest trees cored within the 400m^2 plot. Stand age reclaimed sites: counted from planting year. Natural soils were described using the Canadian System of Soil Classification (Soil Classification Working Group, 1998).

Table 3-2 Main characteristics of the five sampled soil layers. Mean values and standard deviations (parentheses). Lowercase letters (p values ≤ 0.1; Tukey's test) are for interpretation, according to permutational analysis of variance results.

Soil layers*	pH	Moisture content (%)	Total carbon (g kg^{-1})	C:N	^{13}C	^{15}N	Total respiration (µg CO_2-C g^{-1} hr^{-1})	Catabolic Evenness	Total PLFAs (nmol g^{-1})
Nat.FF	6.0a (0.9)	100.7a (19.2)	230.0a (57.0)	20.6a (2.1)	-27.7a (0.7)	0.3b (0.7)	28575.4ab (9894.3)	6.1a (0.6)	1386.2ab (300.8)
Novel.FF	6.6a (0.3)	93.0a (38.5)	293.0a (73.0)	20.0a (2.9)	-28.0a (0.7)	-1.3c (0.9)	36651.8a (18559.7)	6.0a (0.4)	1664.0a (525.5)
FF.PMM-Mid&Old	6.8a (0.4)	21.1b (9.3)	103.0b (44.0)	20.3a (1.8)	-26.1b (1.7)	1.3ab (0.7)	12925.0bc (5259.5)	5.3a (1.5)	1044.9b (398.8)
FF.PMM-Young	6.5a (0.2)	23.7b (1.6)	84.0b (22.0)	19.6a (1.0)	-26.7ab (0.1)	1.0ab (0.4)	6793.0c (2302.4)	5.9a (0.8)	850.8b (447.7)
PMM	6.0a (0.8)	27.3b (11.6)	107.0b (45.0)	18.6a (2.0)	-27.0ab (0.5)	1.6a (0.5)	11047.8c (6184.9)	5.6a (1.3)	832.9b (267.9)

*Nat.FF: forest floor from >30-year natural undisturbed stands; Novel.FF: forest floor from 24-31 year reclaimed stands; FF.PMM-Mid&Old: forest floor + peat-mineral soil mix from 17-31 year reclaimed stands; FF.PMM-Yg: forest floor + peat-mineral soil mix from < 15 year reclaimed stands; PMM: peat-mineral soil mix from 24-31 year reclaimed stands.

Table 3-3 Multi-response permutation procedure (MRPP) results for the PLFA data (mol %) of the five sampled soil layers. The p-values are presented following Bonferroni correction.

	T	A	*p*
Overall	-7.1	0.19	<0.001
Soil layer x soil layer*			
Novel.FF x PMM	-6.3	0.26	0.01
Novel.FF x FF.PMM-Yg	-4.3	0.21	0.03
Novel.FF x FF.PMM-Mid&Old	-3.8	0.11	0.03
Novel.FF x Nat.FF	-3.3	0.1	0.03
PMM x FF.PMM-Mid&Old	-3.3	0.1	0.06
PMM x Nat.FF	-4.4	0.17	0.02
FF.PMM-Yg x PMM	-1.3	0.07	1.00
FF.PMM-Yg x FF.PMM-Mid&Old	-2.8	0.11	0.10
FF.PMM-Yg x Nat.FF	-2.2	0.13	0.29
FF.PMM-Mid&Old x Nat.FF	-1.5	0.05	0.79

*Nat.FF: forest floor from >30-year natural undisturbed stands; Novel.FF: forest floor from 24 31 year reclaimed stands; FF.PMM-Mid&Old: forest floor + peat-mineral soil mix from 17-31 year reclaimed stands; FF.PMM-Yg: forest floor + peat-mineral soil mix from < 15 year reclaimed stands; PMM: peat-mineral soil mix from 24-31 year reclaimed stands.

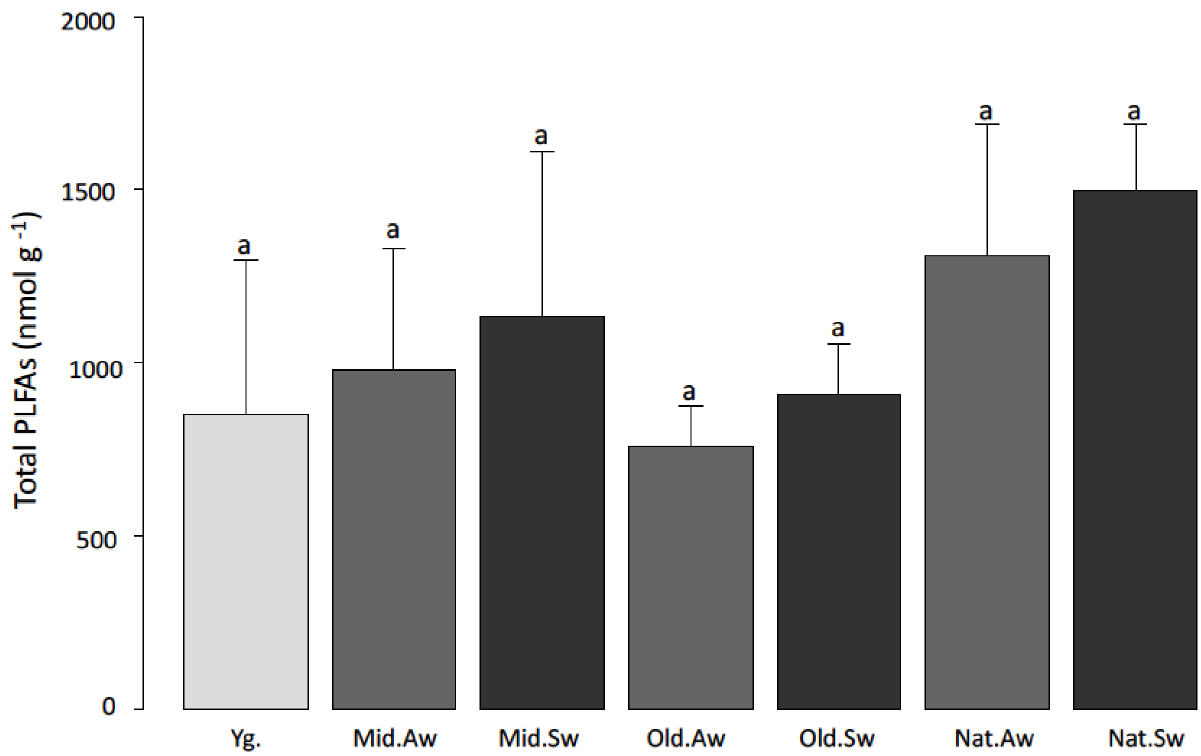
Table 3-4 Total PLFA (nmol g^{-1}) indicator species analysis.

Site	Soil layer	PLFA fidelity	Predominant origin	p-value
Young reclaimed	FF.PMM-Yg.	i15:0	Gram positive bacteria	0.04
Young reclaimed	FF.PMM-Yg.	i17:0	Gram positive bacteria	0.02
Young reclaimed	FF.PMM-Yg.	16:1ω5c	Gram negative bacteria/ Arbuscular mycorrhiza	0.02
Young reclaimed	FF.PMM-Yg.	10Me16:0	Actinomycetes	0.02
Young reclaimed	FF.PMM-Yg.	10Me18:0	Actinomycetes	0.01
Young reclaimed	FF.PMM-Yg.	20:0	Protozoa	0.02
Old reclaimed spruce	Novel.FF	a17:0	Gram positive bacteria	0.01
Natural spruce	Nat.FF	16:1ω7c	Gram negative bacteria	0.03
Natural spruce	Nat.FF	a17:1ω9c	Gram negative bacteria	0.03
Natural spruce	Nat.FF	18:1ω7c	Gram negative bacteria	0.03

*Fidelity: Faithfulness of a PLFA to a site (found at all sites within each site category).

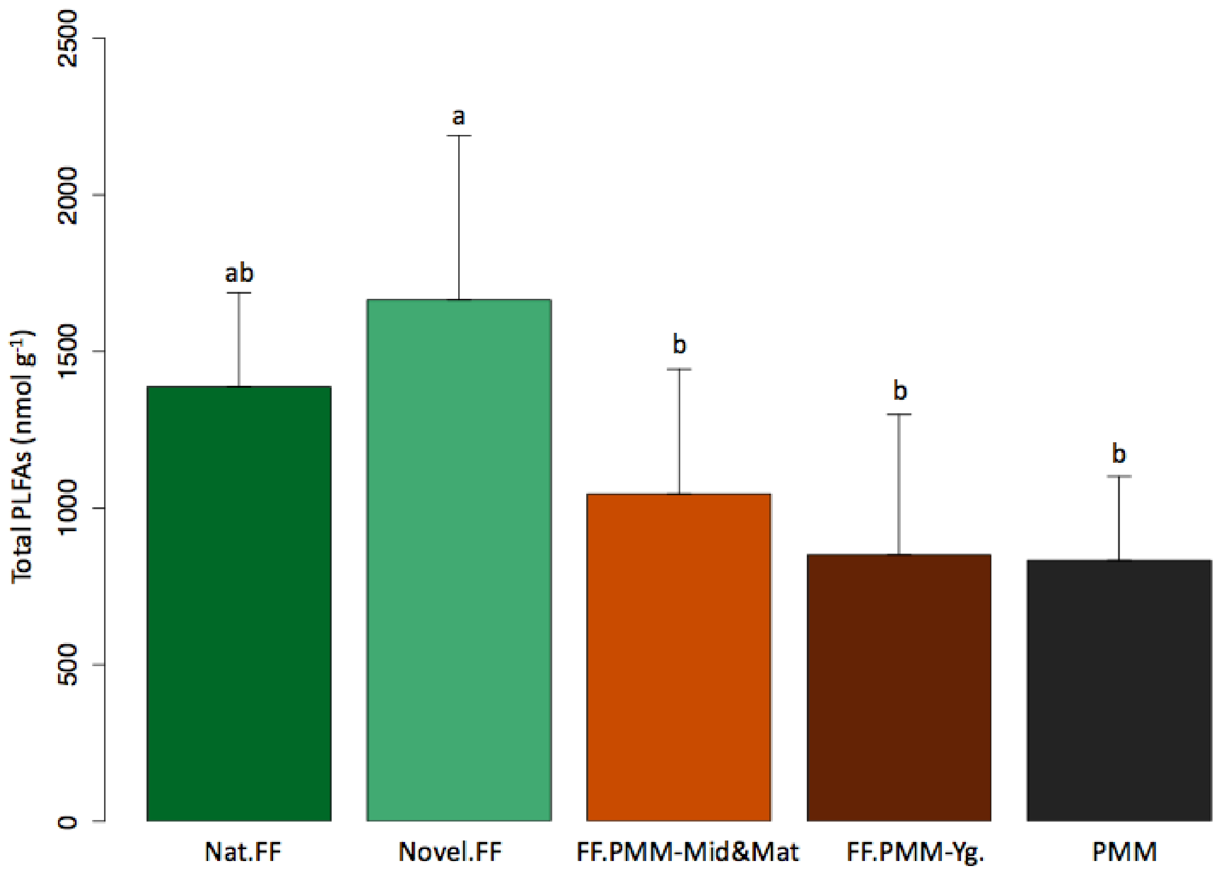
*Gram positive bacteria, protozoa (Kaur et al., 2005; Whalen, 2010; Chang et al. 2017); gram negative bacteria (Zelles, 1997; Zog et al., 1997; Kaur et al., 2005); arbuscular mycorrhizae (Olsson, 1999); actinomycetes (Myers et al., 2001).

Figure 3-1 Total soil PLFAs (nmol g^{-1}) from the reclaimed and natural study sites compared by canopy type and stand age. Similar lowercase letters indicate no significant differences ($p \geq 0.1$; Tukey's test). Error bars represent one standard deviation.



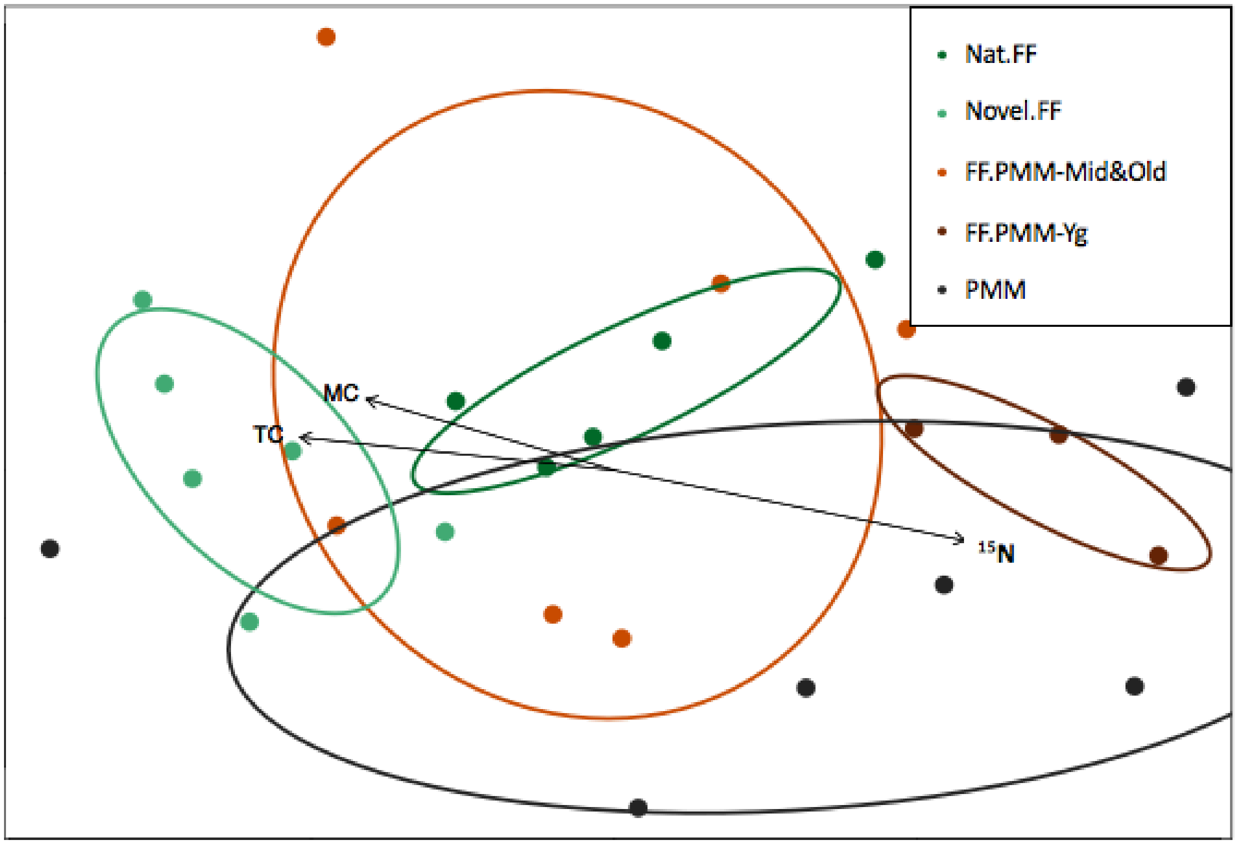
*Yg: reclaimed 8 year mixed stands lacking canopy closure; Mid.Aw: reclaimed 17-27 year aspen stands; Mid.Sw: reclaimed 23-25 year white spruce stands; Old.Aw: reclaimed 30-31 year aspen stands; Old.Sw: reclaimed 30-31 year white spruce stands; Nat.Aw: natural undisturbed 42-60 year aspen stands; Nat.Sw: natural undisturbed 35-103 year white spruce stands.

Figure 3-2 Total soil PLFAs (nmol g^{-1}) from the reclaimed and natural study sites compared among the five sampled soil layers. Different lowercase letters indicate significant differences ($p \leq 0.1$; Tukey's test). Error bars represent one standard deviation.



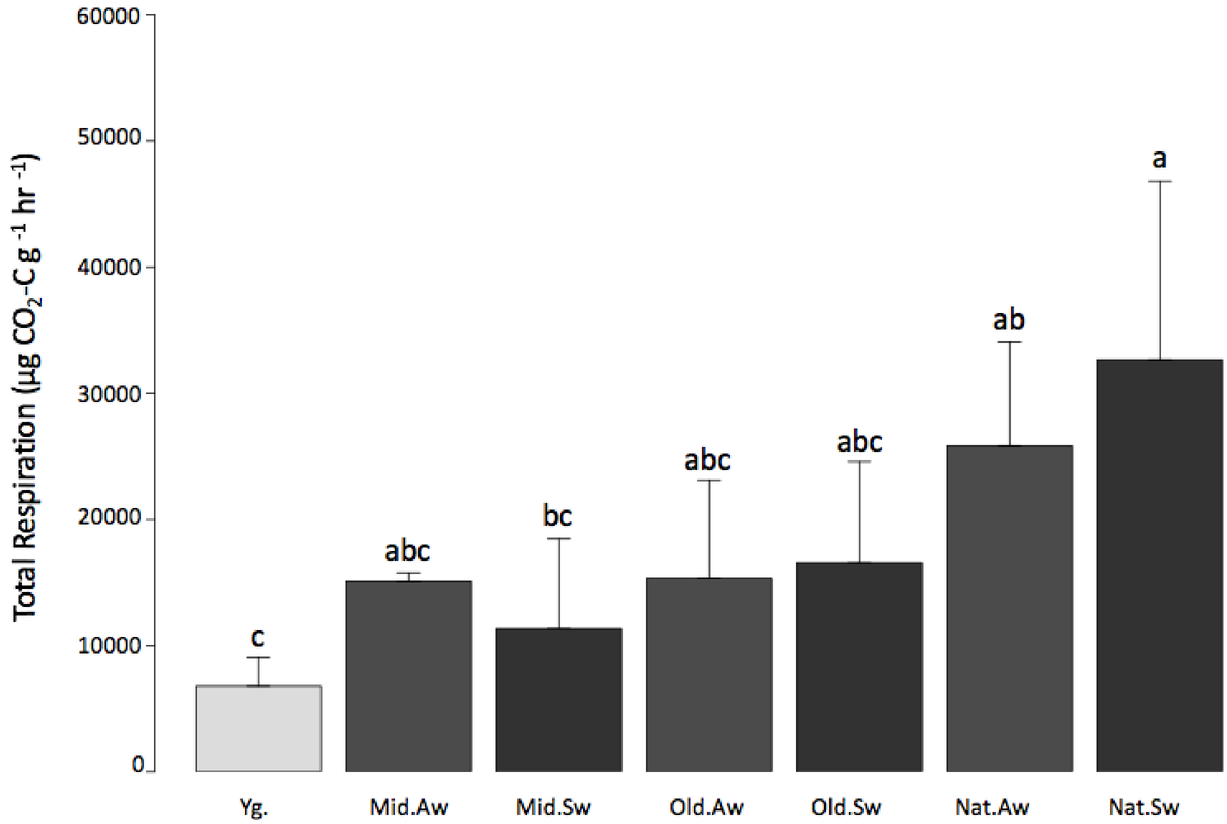
*Nat.FF: forest floor from >30-year natural undisturbed stands; Novel.FF: forest floor from 24 31 year reclaimed stands; FF.PMM-Mid&Old: forest floor + peat-mineral soil mix from 17-31 year reclaimed stands; FF.PMM-Yg: forest floor + peat-mineral soil mix from < 15 year reclaimed stands; PMM: peat-mineral soil mix from 24-31 year reclaimed stands.

Figure 3-3 NMDS ordination of PLFAs (mol %) from the five sampled soil layers. Ellipses are hand drawn to reflect distinct groupings based on MRPP.



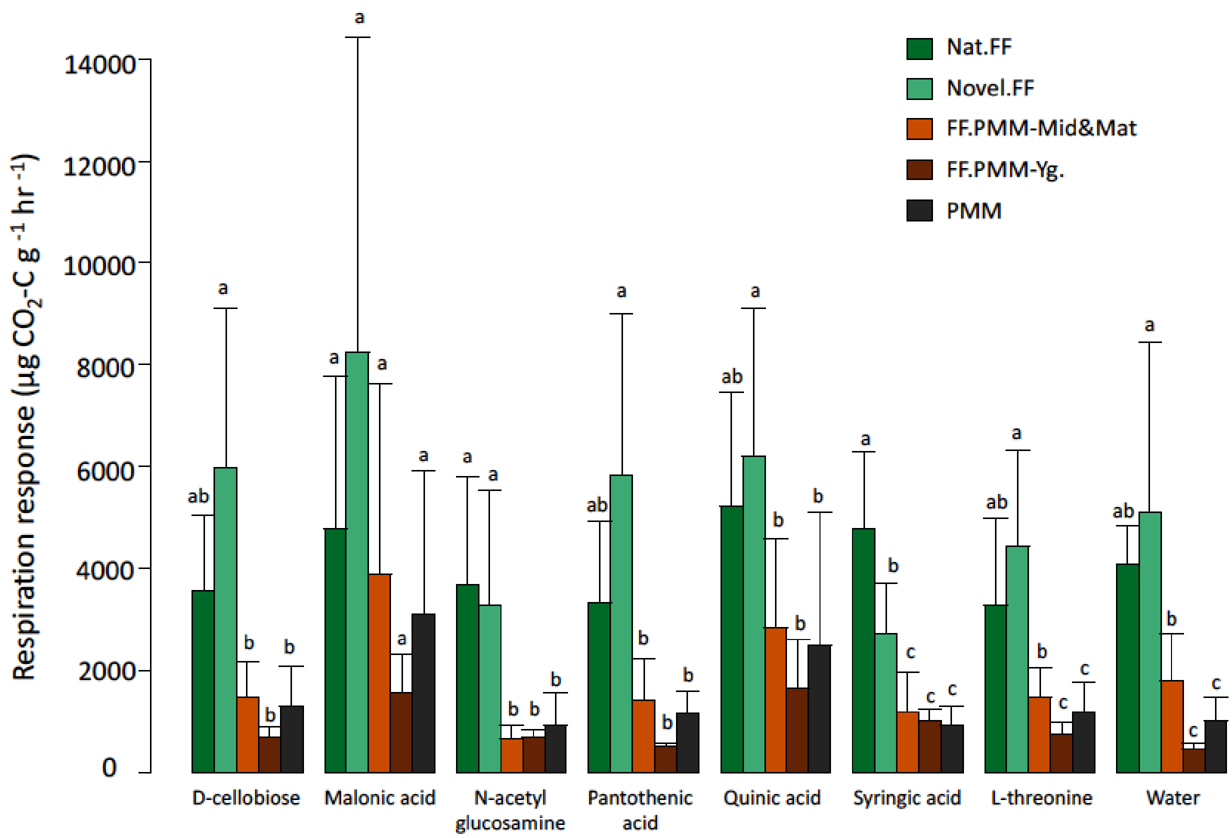
*Nat.FF: forest floor from >30-year natural undisturbed stands; Novel.FF: forest floor from 24 31 year reclaimed stands; FF.PMM-Mid&Old: forest floor + peat-mineral soil mix from 17-31 year reclaimed stands; FF.PMM-Yg: forest floor + peat-mineral soil mix from < 15 year reclaimed stands; PMM: peat-mineral soil mix from 24-31 year reclaimed stands.

Figure 3-4 Total soil microbial respiration (μg CO_2-C g^{-1} hr^{-1}) from the reclaimed and natural study sites compared by canopy type and stand age. Different lowercase letters indicate significant differences ($p \leq 0.1$; Tukey's test). Error bars represent one standard deviation.



*Yg: reclaimed 8 year mixed stands lacking canopy closure; Mid.Aw: reclaimed 17-27 year aspen stands; Mid.Sw: reclaimed 23-25 year white spruce stands; Old.Aw: reclaimed 30-31 year aspen stands; Old.Sw: reclaimed 30-31 year white spruce stands; Nat.Aw: natural undisturbed 42-60 year aspen stands; Nat.Sw: natural undisturbed 35-103 year white spruce stands.

Figure 3-5 Microbial respiration response (μg CO_2-C g^{-1} hr^{-1}) to substrate addition for the five sampled soil layers. Different lowercase letters indicate significant differences ($p \leq 0.1$; Tukey's test).



*Nat.FF: forest floor from >30-year natural undisturbed stands; Novel.FF: forest floor from 24 31 year reclaimed stands; FF.PMM-Mid&Old: forest floor + peat-mineral soil mix from 17-31 year reclaimed stands; FF.PMM-Yg: forest floor + peat-mineral soil mix from < 15 year reclaimed stands; PMM: peat-mineral soil mix from 24-31 year reclaimed stands.

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4. CHAPTER 4 – SUMMARY AND CONCLUSIONS

The overall objectives of this MSc thesis were to: (1) examine how tree cover influences soil microbial structure and function, and (2) examine how disturbance type (surface mining vs. clearcut harvesting) influences soil microbial structure and function.

I hypothesized that:

(1) undisturbed aspen forests would have a greater microbial biomass than spruce forests, and the two forests would harbor different soil microbial communities due to the differences in tree litter quality,

(2) higher severity disturbance (mining) would result in lower microbial biomass, and greater change in function than clearcutting due to a more severe change of environment; however, under both disturbance regimes, the microbial community would adapt to their new surroundings and evolve towards the undisturbed communities with time, and

(3) microbial recovery would proceed at a faster rate under more rapid growing aspen than under spruce, and that the functional diversity of soil microbes would evolve in parallel to tree establishment.

At EMEND, undisturbed aspen and spruce forest floors supported microbial communities with comparable biomass and microbial function, yet different structure. Variation in structure was attributed to differences in leaf litter quality and quantity. In the AOSR, there were no effects of stand type on microbial total biomass, total respiration, or community structure across undisturbed stands. It is possible that the influence of tree species was confounded by other site factors such as pH and the absence of an H layer in reclaimed stands.

The results of the study are in agreement with our hypothesis that surface mining, a higher severity disturbance would result in lower microbial biomass and greater change of function. In the AOSR, microbial biomass in the forest floor layers containing peat ranged from 833–1044 nmol g^{-1}, while the novel forest floor reached 1664 nmol g^{-1}. At EMEND clearcut spruce and aspen forest floors had double the microbial biomass, ranging from 4004-4065 nmol g^{-1}. Furthermore, the effects of harvest on microbial community function disappeared 4.5 years post-harvest (Hannam et al. 2006), while it took approximately 30 years for a novel forest floor to develop and reach total respiration levels comparable to natural forest floors in the AOSR.

The results of the study are also in agreement with our hypothesis that microbial recovery would proceed at a faster rate under aspen stands and the functional diversity of soil microbes would evolve parallel to tree establishment. In the AOSR, novel forest floor development was greatest in sites dominated by aspen. The development of the novel forest floor was key to the re-establishment of microbial community function. At EMEND, microbial community function evolved parallel to tree development, however it is unknown if microbial recovery would proceed at a faster rate under aspen stands compared to spruce stands because aspen regenerated in both aspen and spruce clearcuts.

4.1 Timber harvesting summary

Phospholipid fatty acid (PLFA) analysis and multiple substrate induced respiration (MSIR) were used to compare total microbial biomass and community structure and function in forest floors from trembling aspen and white spruce dominated stands that were clearcut or left undisturbed. The present study followed work conducted by K.D Hannam in 2004, 5.5 years post-harvest, allowing for the comparison of microbial communities 5.5 years to 17.5 years post-harvest.

The first objective of this study was to determine if microbial biomass, structure and function differed between the two undisturbed stand types. PLFA and MSIR analyses revealed that aspen and spruce forest floors supported microbial communities with comparable biomass (nmol g^{-1}) and microbial function (μg CO_2-C g^{-1} hr^{-1}), yet different microbial structure (mol % PLFA). The difference in microbial community structure was attributed to differences in leaf litter quantity and quality. Aspen stands had higher leaf litter cover, pH, total carbon and nitrogen, and catabolic evenness. Spruce stands had higher moss and needle cover, C/N ratio, and ^{13}C.

The second objective of this study was to determine if microbial biomass, structure and function of clearcut harvest stands resembled those of undisturbed stands. The classic successional trajectory following wildfire is broadleaf- to mixed to conifer dominated forests. Aspen was the dominant tree species regenerating in both aspen and spruce clearcuts, indicating the legacy effect of the aspen parent stand in both clearcuts. The microbial communities of undisturbed *vs.* clearcut forest floors of both aspen and spruce stands had similar total biomass and total respiration, yet a different structural composition. Again, microbial structure was likely affected by leaf litter quality and quantity. Clearcut spruce and aspen stands were essentially an aspen monoculture, while undisturbed stands had >70 % aspen or spruce, and other species to a lesser extent. At EMEND, harvesting effects on microbial biomass were apparent 2.5 years post-harvest in both aspen and spruce stands (Lindo & Visser, 2003), however 3.5, 5.5 (Jerabkova et al., 2006; Hannam et al. 2006) and 17.5 years post-harvest those differences were no longer evident. Harvesting effects on microbial function were also not apparent 5.5 years and 17.5 years post-harvest. Rapid recovery of microbial biomass and function can be attributed to winter harvesting when the ground is frozen to minimize the effect of disturbance on the forest floor and their microbial communities.

The final objective of this study was to determine if microbial biomass, structure and function varied between the two post-harvest stand types. With aspen re-growing in clearcuts of both aspen and spruce it was not surprising that both sites had similar leaf area index, ground cover of leaf litter, shrubs, and live vegetation, and forest floor thickness, bulk density and ^{15}N These factors in addition to minimal forest floor disturbance likely attributed to similarities in microbial total biomass and function between clearcut sites. There were differences in pH, total carbon and nitrogen, and ^{13}C, indicating the legacy effect of spruce forest floors, which likely accounted for differences in microbial community structure.

4.1.1 Management recommendations for timber harvesting

Clearcutting did not considerably change the structure of the forest floor microbial community 5.5 years post-harvest. However, 17.5 years post-harvest microbial community structure had changed due to the natural regeneration of aspen within historically spruce dominated sites. Given that litter quality and quantity have been shown to affect microbial community composition (Priha et al., 2001; Grayston & Prescott, 2005: Hannam et al. 2006; Freedman & Zak, 2015), which has the potential to alter biogeochemical cycling (Bradley et al., 1997; Priha et al., 1999; Thomas & Prescott, 2000) there is the potential to alter nutrient cycling and ecosystem productivity in regenerating stands.

Clearcutting did not significantly alter the size of the forest floor microbial community or its function 5.5 years or 17.5 years post-harvest. These results indicate the importance of winter harvesting when the ground is frozen to minimize soil disturbance. Although the effects of clearcutting on the soil microbial community were minimal in this case, there have been many studies at EMEND that outline the positive effects of variable retention harvest, a silviculture technique that emulates natural disturbance, on numerous components of the ecosystem. Maintaining the spatial distribution of different tree species by varying the retention levels across the landscape provides a seed bank for natural regeneration (Martin-DeMoor et al. 2010; Solarik et al. 2010), and has been shown to maintain forest-specialists of songbirds (Harrison et al. 2005), bumble bees and the understory plants they are associated with (Chávez and Macdonald 2010; Pengelly and Carter 2010), bryophytes (Caners et al., 2013), slugs and snails (Abele et al. 2010), parasitoid wasps (Schwarzfeld and Sperling 2012) spiders (Pinzon et al. 2013), and beetles (Work et al. 2010).

4.1.2 Future research in timber harvesting

At EMEND, the present study analyzed the effects of clearcutting on soil microbial communities in forest floors of stands dominated by both aspen and white spruce 17.5 years post-harvest, and compared them to K.D. Hannam's results 5.5 years post-harvest. However the study conducted by Hannam et al. (2006) was much larger in scope and monitored the effects of clearcutting in mixed stands of coniferous and deciduous species, as well as partial harvests in which 50% or 20% of the original stand was retained in stand types of aspen, white spruce, or a mix of the two. A future study resampling all the sites initially sampled by K.D. Hannam would be valuable in terms of the empirical knowledge gained on stand dynamics and soil microbial communities in three different stand types following clearcut and partial harvest.

4.2 Athabasca oil sands summary

Phospholipid fatty acid (PLFA) and multiple substrate induced respiration (MSIR) analyses were used to characterize total microbial biomass and community structure and function in forest floors from trembling aspen (*Populus tremuloides*) and white spruce (*Picea glauca*) dominated stands that were undergoing reclamation following surface mining.

The first objective of this study was to assess the importance of time since reclamation on microbial recovery by comparing forest floor microbial communities in reclaimed stands to their mature undisturbed counterparts. Microbial biomass (total PLFAs nmol g^{-1}) did not show any clear relationship with time since reclamation. Our youngest reclaimed site was 8 years. It is possible that microbial biomass had recovered 8 years post-reclamation. There was however, an increase in total respiration (μg CO_2-C g^{-1} hr^{-1}) from young to old reclaimed sites where levels became comparable to natural forest floors. Taken together, our results indicate that while the size of the microbial communities did not follow any clear pattern, the activity of the microbial community reached levels comparable to natural forest floors after 30 years.

The second objective of this study was to assess the importance of canopy type on microbial recovery by comparing forest floor microbial communities in undisturbed and reclaimed stands of both aspen and white spruce. Unexpectedly, there were no effects of stand type on microbial total biomass, total respiration, or community structure across or within stands. It is possible that the influence of tree species was confounded by other site factors such as pH and the absence of an H layer in reclaimed stands.

The final objective of this research was to assess the effect of different soil materials on microbial biomass, and community structure and function. The forest floor materials, regardless of whether they were sampled from the reclaimed sites or the natural forests exhibited a greater microbial biomass and higher respiration response to substrate addition than the peat-based materials. This is likely due to the higher carbon concentrations, and newer more labile carbon source in the forest floor. Similarly, to total PLFAs and total respiration, the structural composition of the forest floor microbial communities was statistically different from that of the peat materials. Moisture and carbon contents were higher in the forest floors and this likely contributed to the observed structural differences between forest floor and peat-based materials.

4.2.1 Management recommendations for the Athabasca oil sands

Re-establishing a soil microbial community with similar functional abilities to communities within natural soils was dependent on the development of a novel forest floor. Future management practices should focus on methods to expedite forest floor development. In our study, there was greater forest floor development in aspen stands compared to spruce stands. Aspen stands are faster-growing, provide more annual litter, and allow greater light transmission to the forest floor than spruce stands (Constabel and Lieffers, 1996; Bergeron et al., 2014). Forest floors of deciduous litter generally have a greater pH and lower C/N ratio (Man and Lieffers, 1999; Priha et al., 2001; Jerabkova et al., 2006). Higher litter quality and light transmission in aspen stands promotes greater shrub cover, richness, and diversity (Macdonald and Fenniak, 2007). Creating stands dominated by aspen, or mixedwoods stands rather than spruce dominated stands would promote fast tree growth and greater shrub cover, both contributing to accelerated forest floor development.

4.2.2 Future research in the Athabasca oil sands

The reclaimed sites in our study ranged from 8-31 years. It would be beneficial to continue monitoring stand dynamics and soil microbial communities for at least one stand rotation (80-100 years) to assess if the structure of microbial communities becomes more similar to natural stands within the forest floor developing at the reclaimed sites, if the function of microbial communities remains similar to natural stands, and if the microbial community continues to support the above-ground vegetation. Our study focused on stands dominated by either aspen or white spruce. It would also be beneficial to study stands dominated by other native boreal tree species, and mixedwood stands to see which stand type provides the fastest forest floor development.

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Appendix 1. EMEND site and soil descriptions

EMEND Site & Soil Assessment									
Site: 1A-Compt A 850		Date: June 17, 16		GPS Coordinates: N: 56˚44'49.7" W: 118˚19'14.9"					
Slope (%)	N: 3		E: 0		S: 1		W: 3		
Slope (˚)	N: -5		E: 0		S: -2		W: -5		
Slope position (lower, mid, upper): Mid-Upper					Aspect (facing & deg.) N facing				
Elevation (m) 773									
Dominant tree species: Aw			Number of dominant trees: Too many to count					Record DBH below	
Centre	7.6								
N	5.8								
E	7.5								
S	8.5								
W	6								
Site Average:	7.08								
Ground cover (%) in a 1m x 1m square:		lichen	moss	leaf litter	needles	bare soil	CWD/Twigs	Total Live	Total Shrubs
	N	0	1	100	0	0	0	50	25
	E	0	0	100	0	0	0	30	30
	S	0	0	100	0	0	0	30	28
	W	0	1	100	0	0	10	75	20
	Site Average	0	0.5	100	0	0	2.5	46.25	25.75
Sampling location distance to nearest tree (cm):	N	53							
	E	40							
	S	30							
	W	75							
	Site Average	49.5							

Plants	Common name	Latin name with authority	
N	Lowbush cranberry	*Viburnum edule*	(Michx.) Raf.
	Twinflower	*Linnaea borealis*	L.
	Prickly rose	*Rosa acicularis*	Lindl.
	Creamy peavine	*Lathyrus ochroleucus*	Hook.
	Dewberry	*Rubus pubescens*	Raf.
	Wild strawberry	*Fragaria virginiana*	Duchesne
	Coltsfoot spp.	*Petasites*	spp.
	Bishop's cap	*Mitella nuda*	L.
	Canada buffaloberry	*Shepherdia canadensis*	(L.) Nutt
	Bryophyte spp.	*Plagiomnium*	spp.
	Bryophyte spp.	*Brachythecium*	spp.
E	Prickly rose	*Rosa acicularis*	Lindl.
	Lowbush cranberry	*Viburnum edule*	(Michx.) Raf.
	Twinflower	*Linnaea borealis*	L.
	Coltsfoot spp.	*Petasites*	spp.
S	Prickly rose	*Rosa acicularis*	Lindl.
	Lowbush cranberry	*Viburnum edule*	(Michx.) Raf.
	Twinflower	*Linnaea borealis*	L.
	Gooseberry	*Ribes*	spp.
W	Prickly rose	*Rosa acicularis*	Lindl.
	Twinflower	*Linnaea borealis*	L.
	Bunchberry	*Cornus canadensis*	L.
	Fireweed	*Chamerion angustifolium*	(L.) Holub
	Violet spp.	*Viola*	spp.
	Prairie crocus	*Anemone patens*	L.
	Currant spp.	*Ribes*	spp.
	Bryophyte spp.	Unknown	
	Saskatoon	*Amelanchier alnifolia*	(Nutt.) Nutt. ex M. Roemer.

EMEND Site & Soil Assessment									
Site: 1B- Compt A 850		Date: June 17, 16	GPS Coordinates: N: 56˚44'52.9" W: 118˚19'13.2"						
Slope (%)	N: 0		E: 0.5		S: 2.5		W: 0.5		
Slope (˚)	N: 0		E: -1		S: -4		W: -1		
Slope position (lower, mid, upper): Mid					Aspect (facing & deg.) NE Facing 30˚				
Elevation (m)	776								
Dominant tree species: Aw			Number of dominant trees: Too many				Record DBH below		
Centre	4.0								
North	5.8								
East	4.2								
South	7.0								
West	8.8								
Site average	5.96								
Ground cover (%) in a 1m x 1m square:		lichen	moss	leaf litter	needles	bare soil	CWD/Twigs	Total Live	Total Shrubs
	N	0	Trace	85	0	0	0	75	0
	E	0	0	100	0	0	0	70	5
	S	0	Trace	100	0	0	0	1	0
	W	0	0	100	0	0	0	50	0
	Site Average	0	0	96.25	0	0	0	49	1.25
Sampling location distance to nearest tree (cm):	N	63							
	E	90							
	S	43							
	W	60							
	Site Average	64							

Plants	**Common name**	**Latin name with authority**
N	Grass spp.	*Poaceae spp.*
	Coltsfoot spp.	*Petasites* spp.
	Moss spp.	Unknown
	Tall lungwort	*Mertensia paniculata* (Aiton) G. Don
E	Red and white baneberry	*Actaea rubra* (Ait.) Willd.
	Coltsfoot spp.	*Petasites* spp.
	Prickly rose	*Rosa acicularis* Lindl.
	Tall lungwort	*Mertensia paniculata* (Aiton) G. Don
S	Bryotheceum?	
	Grass spp.	*Poaceae spp.*
	Coltsfoot spp.	*Petasites* spp.
	Tall lungwort	*Mertensia paniculata* (Aiton) G. Don
W	Meadow horsetail	*Equisetum pratense* Ehrh.
	Coltsfoot spp.	*Petasites* spp.
	Lowbush cranberry	*Viburnum edule* (Michx.) Raf.
	Wintergreen spp.	*Pyrola spp.*
	Grass spp.	*Poaceae spp.*
	Tall lungwort	*Mertensia paniculata* (Aiton) G. Don

EMEND Site & Soil Assessment									
Site: 1C-Compt A 850		Date: June 18, 16		GPS Coordinates: N: 56˚44'59.8" W: 118˚19'26.6"					
Slope (%)	N: 4		E: 4		S: 5		W: 1		
Slope (˚)	N: 2		E: 2		S: 3		W: 0.5		
Slope position (lower, mid, upper): lower-mid					Aspect (facing & deg.) East / 92˚				
Elevation (m) 773									
Dominant tree species: Aw			Number of dominant trees: Too many to count				Record DBH below		
Centre	9.3								
N	6.9								
E	5.2								
S	8.4								
W	3.8								
Site average	6.72								
Ground cover (%) in a 1m x 1m square:		lichen	moss	leaf litter	needles	bare soil	CWD/~~Twigs~~	Total Live	Total Shrubs
	N	0	0	100	0	0	0	1	0
	E	0	0	100	0	0	0	15	10
	S	0	0	100	0	0	0	10	1
	W	0	0	100	0	0	0	15	10
	Site Average	0	0	100	0	0	0	10.25	5.25
Sampling location distance to nearest tree (cm):	N	70	Notes: Lots of Alder here; therefore, higher moisture than 1A and 1B						
	E	30							
	S	50							
	W	75							
	Site Average	56.25							

Plants	**Common name**	**Latin name with authority**
N	Bunchberry	*Cornus canadensis* L.
	Prickly rose	*Rosa acicularis* Lindl.
	Lowbush cranberry	*Viburnum edule* (Michx.) Raf.
E	Prickly rose	*Rosa acicularis* Lindl.
	Lowbush cranberry	*Viburnum edule* (Michx.) Raf.
	Bunchberry	*Cornus canadensis* L.
	Twinflower	*Linnaea borealis* L.
	Grass spp.	*Poaceae spp.*
	Fungi spp.	Unknown
	Wild strawberry	*Fragaria virginiana* Duchesne
S	Wild strawberry	*Fragaria virginiana* Duchesne
	Prickly rose	*Rosa acicularis* Lindl.
	Lowbush cranberry	*Viburnum edule* (Michx.) Raf.
	Twinflower	*Linnaea borealis* L.
	Palmate-leaved coltsfo	*Petasites palmatus* (Ait.) Cronq.
	Fireweed	*Chamerion angustifolium* (L.) Holub
W	Asteraceae spp.	Unknown
	Prickly rose	*Rosa acicularis* Lindl.
	Lowbush cranberry	*Viburnum edule* (Michx.) Raf.
	Twinflower	*Linnaea borealis* L.
	Grass spp.	*Poaceae spp.*

EMEND Site & Soil Assessment										
Site: 2A-Compt B: 864		Date: June 22, 16		GPS Coordinates: N: 56.75176 W: 118. 36149						
Slope (%)	N: -3		E: 4		S: 11		W: 6			
Slope (˚)	N: 1.5		E: 2.5		S: 6		W: 3.5			
Slope position (lower, mid, upper):					Aspect (facing & deg.) S Facing 172˚					
Elevation (m) 831										
Dominant tree species: Aw			Number of dominant trees: 75% Aw				Record DBH below			
Centre	8.5									
N	5.5									
E	6.4									
S	6.3									
W	5.8									
Site average	6.5									
Secondary tree species: Pb			Number of secondary trees: 25% Pb							
Ground cover (%) in a 1m x 1m square:		lichen	moss	leaf litter	needles	bare soil	CWD/Twigs	Total Live	Total Shrubs	
	N	0	0	100	0	0	0	25	20	
	E	0	Trace	100	0	0	0	40	5	
	S	0	Trace	100	0	0	3	40	25	
	W	0	0	100	0	0	Trace	40	30	
	Site Average	0	0	100	0	0	1	36.25	20	
Sampling location distance to nearest tree (cm):	N	40 Aw								
	E	25 Pb								
	S	78 Aw								
	W	30 Aw								
	Site Average	43.25								

Plants	Common name	Latin name with authority
N	Lowbush cranberry	*Viburnum edule* (Michx.) Raf.
	Bunchberry	*Cornus canadensis* L.
	Grass spp.	*Poaceae spp.*
	Creamy peavine	*Lathyrus ochroleucus* Hook.
	Palmate-leaved coltsfoot	*Petasites palmatus* (Ait.) Cronq.
E	Bunchberry	*Cornus canadensis* L.
	Baby Sw	*Picea spp.*
	Cow parsnip	*Heracleum lanatum* Michx.
	Baby alder	*Alnus spp.*
	Bishop's cap	*Mitella nuda* L.
	Wild strawberry	*Fragaria virginiana* Duchesne
	Wild red raspberry	*Rubus idaeus L.*
S	Lowbush cranberry	*Viburnum edule* (Michx.) Raf.
	Grass spp.	*Poaceae spp.*
	Cow parsnip	*Heracleum lanatum* Michx.
	Moss spp.	Unknown
	Asteraceae spp.	Unknown
W	Lowbush cranberry	*Viburnum edule* (Michx.) Raf.
	Baby Pb	*Betula spp.*
	Wild strawberry	*Fragaria virginiana* Duchesne
	Prickly rose	*Rosa acicularis* Lindl.
	Sweet-scented bedstraw	*Galium triflorum* Michx.

EMEND Site & Soil Assessment									
Site: 2B-Compt: 864		Date: June 22, 16		GPS Coordinates: N: 56. 75084 W: 118.36208					
Slope (%)	N: 9		E: 9		S: 11		W: 10		
Slope (˚)	N: 5		E: 5		S: 6		W: 5.5		
Slope position (lower, mid, upper): Mid					Aspect (facing & deg.) W Facing 288˚				
Elevation (m) 841									
Dominant tree species: Aw			Number of dominant trees: Many 75% of the stand is Aw						
Centre	9.1								
N	8.6								
E	7.0								
S	4.8								
W	7.0								
Site average	7.3								
Secondary tree species: Pb			Number of secondary trees: 25% of stand = Balsam Poplar						
Ground cover (%) in a 1m x 1m square:		lichen	moss	leaf litter	needles	bare soil	CWD/Twigs	Total Live	Total Shrubs
	N	0	0	100	0	0	8	10	10
	E	0	Trace	100	0	0	0	3	0
	S	0	Trace	100	0	0	5	3	0
	W	0	0	100	0	0	0	40	5
	Site Average	0	0	100	0	0	3.25	14	3.75
Sampling location distance to nearest tree (cm):	N	50cm Balsam Poplar		Notes: Appears to be at least 1 Sw stump					
	E	155cm Pb							
	S	50cm Aw							
	W	50cm Aw							
	Site Average	76.25							

Plants	**Common name**	**Latin name with authority**
N	Lowbush cranberry	*Viburnum edule* (Michx.) Raf.
	Bishop's cap	*Mitella nuda* L.
E	Bishop's cap	*Mitella nuda* L.
	Northern bedstraw	*Galium boreale* L.
	Grass spp.	*Poaceae spp.*
	Moss spp.	*Unknoqn*
S	Grass spp.	*Poaceae spp.*
	Moss spp.	*Unknown*
W	Lowbush cranberry	*Viburnum edule* (Michx.) Raf.
	Bishop's cap	*Mitella nuda* L.
	Grass spp.	*Poaceae spp.*
	Red and white baneberry	*Actaea rubra* (Ait.) Willd.
	Currant spp.	*Ribes* spp.
	Meadow horsetail	*Equisetum pratense* Ehrh.
	Bunchberry	*Cornus canadensis* L.
	Arrow-leaved coltsfoot	*Petasites sagittatus* Pursh.

EMEND Site & Soil Assessment									
Site: 2C-Compt. 864		Date: June 22, 16		GPS Coordinates: N: 56.74856 W: 118.36148					
Slope (%)	N: 14		E: 20		S: 15		W: 15		
Slope (˚)	N: 7.5		E: 11.5		S: 8.5		W: 8.5		
Slope position (lower, mid, upper):					Aspect (facing & deg.) NW Facing 308˚				
Elevation (m)	844								
Dominant tree species: Aw			Number of dominant trees:				Record DBH below		
Centre	6.8								
N	3.3								
E	5.2								
S	5.5								
W	5.2								
Site average	5.2								
Ground		lichen	moss	leaf litter	needles	bare soil	CWD/Twigs	Total Live	Total Shrubs
cover (%) in	N	0	0	100	0	0	0	25	10
a 1m x 1m	E	0	0	100	0	0	0	40	25
square:	S	0	Trace	100	0	0	0	10	5
	W	0	Trace	100	0	0	0	30	25
	Site Average	0	0	100	0	0	0	26.25	16.25
Sampling	N	70	Notes: there is 1 sw stump in the plot						
location	E	68							
distance to	S	120							
nearest tree	W	40							
(cm):	Site Average	74.5							

Plants	**Common name**	**Latin name with authority**
N	Liliaceae spp.	*Lilium spp.*
	Wintergreen spp.	*Pyrola spp.*
	Lowbush cranberry	*Viburnum edule* (Michx.) Raf
	Bishop's cap	*Mitella nuda* L.
	Wild red raspberry	*Rubus idaeus L.*
	Red and white baneberry	*Actaea rubra* (Ait.) Willd.
E	Lowbush cranberry	*Viburnum edule* (Michx.) Raf
	Bishop's cap	*Mitella nuda* L.
	Grass spp.	*Poaceae spp.*
	Northern bedstraw	*Galium boreale* L.
	Liliaceae spp.	*Lilium spp.*
S	Anemone spp.	*Anemone spp.*
	Trailing raspberry	*Rubus pubescens* Raf.
	Bishop's cap	*Mitella nuda* L.
	Grass spp.	*Poaceae spp.*
	Moss spp.	Unknown
	Arrow-leaved coltsfoot	*Petasites sagittatus* Pursh.
W	Bishop's cap	*Mitella nuda* L.
	Creamy peavine	*Lathyrus ochroleucus* Hook.
	Grass spp.	*Poaceae spp.*
	Wintergreen spp.	*Pyrola spp.*
	Liliaceae spp.	*Lilium spp.*
	Bunchberry	*Cornus canadensis* L.
	Cow parsnip	*Heracleum lanatum* Michx.

EMEND Site & Soil Assessment									
Site: 3A-Comp I: 941		Date: June 28, 16		GPS Coordinates: N: 56.81749 W: 118.37160					
Slope (%)	N: 3		E: 5			S: 5		W: 4	
Slope (˚)	N: 1.5		E: 3			S: 3		W: 2.5	
Slope position (lower, mid, upper):						Aspect (facing & deg.)			
Elevation (m)	702								
Dominant tree species: Aw			Number of dominant trees: Too many				Record DBH below		
Centre	7.5								
N	6.8								
E	5.7								
S	7.8								
W	6.6								
Site average	6.88								
Ground cover (%) in a 1m x 1m square:		lichen	moss	leaf litter	needles	bare soil	CWD/Twigs	Total Live	Total Shrubs
	N	0	0	100	0	0	0	20	5
	E	0	0	100	0	0	0	60	40
	S	0	0	100	0	0	0	25	0
	W	0	0	100	0	0	0	80	40
	Site Average	0	0	100	0	0	0	46.25	21.25
Sampling location distance to nearest tree (cm):	N	35							
	E	75							
	S	85							
	W	110							
	Site Average	76.25							

Plants	**Common name**	**Latin name with authority**
N	Palmate-leaved coltsfoot	*Petasites palmatus* (Ait.) Cronq.
	Grass spp.	*Poaceae spp.*
	Wild strawberry	*Fragaria virginiana* Duchesne
	Wild Vetch	*Vicia americana* L.
	Northern bedstraw	*Galium boreale* L.
	Fireweed	*Chamerion angustifolium* (L.) Holub
	Lowbush cranberry	*Viburnum edule* (Michx.) Raf.
E	Palmate-leaved coltsfoot	*Petasites palmatus* (Ait.) Cronq.
	Grass spp.	*Poaceae spp.*
	Northern bedstraw	*Galium boreale* L.
	Fireweed	*Chamerion angustifolium* (L.) Holub
	Lowbush cranberry	*Viburnum edule* (Michx.) Raf.
	Saskatoon	*Amelanchier alnifolia* (Nutt.) Nutt. ex M. Roemer
	Common Yarrow	*Achillea millefolium* L.
	Bunchberry	*Cornus canadensis* L.
	Prickly rose	*Rosa acicularis* Lindl.
	Liliaceae spp.	*Lilium spp.*
	Twinflower	*Linnaea borealis* L.
S	Palmate-leaved coltsfoot	*Petasites palmatus* (Ait.) Cronq.
	Grass spp.	*Poaceae spp.*
	Fireweed	*Chamerion angustifolium* (L.) Holub
W	Palmate-leaved coltsfoot	*Petasites palmatus* (Ait.) Cronq.
	Grass spp.	*Poaceae spp.*
	Northern bedstraw	*Galium boreale* L.
	Fireweed	*Chamerion angustifolium* (L.) Holub
	Lowbush cranberry	*Viburnum edule* (Michx.) Raf.
	Common Yarrow	*Achillea millefolium* L.
	Prickly rose	*Rosa acicularis* Lindl.
	Liliaceae spp.	*Lilium spp.*
	Creamy peavine	*Lathyrus ochroleucus* Hook.
	Wintergreen spp.	*Pyrola spp.*

EMEND Site & Soil Assessment									
Site: 3B-Compt I: 941		Date: June 28, 16		GPS Coordinates: N: 56.81915 W: 118.36877					
Slope (%)	N: 4		E: 5		S: 3		W: 3		
Slope (˚)	N: 2.5		E: 3		S: 1.5		W: 1.5		
Slope position (lower, mid, upper): lower/mid					Aspect (facing & deg.) SE Facing 132˚				
Elevation (m)	708								
Dominant tree species: Aw			Number of dominant trees:				Record DBH below		
Centre	10.8								
N	10.3								
E	7.0								
S	7.5								
W	7.8								
Site average	8.7								
Ground cover (%) in a 1m x 1m square:		lichen	moss	leaf litter	needles	bare soil	CWD/Twigs	Total Live	Total Shrubs
	N	0	Trace	100	0	0	0	25	10
	E	0	0	100	0	0	0	50	40
	S	0	0	100	0	0	0	40	35
	W	0	0	100	0	0	0	30	10
	Site Average	0	0	100	0	0	0	36.25	23.75
Sampling location distance to nearest tree (cm):	N	40							
	E	70							
	S	50							
	W	80							
	Site Average	60							

Plants	Common name	Latin name with authority
N	Grass spp.	*Poaceae spp.*
	Northern bedstraw	*Galium boreale* L.
	Fireweed	*Chamerion angustifolium* (L.) Holu
	Lowbush cranberry	*Viburnum edule* (Michx.) Raf.
	Prickly rose	*Rosa acicularis* Lindl.
E	Grass spp.	*Poaceae spp.*
	Fireweed	*Chamerion angustifolium* (L.) Holu
	Lowbush cranberry	*Viburnum edule* (Michx.) Raf.
	Prickly rose	*Rosa acicularis* Lindl.
	Liliaceae spp.	*Lilium spp.*
	Wild red raspberry	*Rubus idaeus L.*
S	Grass spp.	*Poaceae spp.*
	Northern bedstraw	*Galium boreale* L.
	Lowbush cranberry	*Viburnum edule* (Michx.) Raf.
	Bunchberry	*Cornus canadensis* L.
	Prickly rose	*Rosa acicularis* Lindl.
	Creamy peavine	*Lathyrus ochroleucus* Hook.
	Asteraceae spp.	Unknown
W	Grass spp.	*Poaceae spp.*
	Bunchberry	*Cornus canadensis* L.
	Prickly rose	*Rosa acicularis* Lindl.
	Wintergreen spp.	*Pyrola spp.*
	Wild red raspberry	*Rubus idaeus L.*
	Bishop's cap	*Mitella nuda* L.

EMEND Site & Soil Assessment									
Site: 3C-Compt I: 941		Date: June 28, 16		GPS Coordinates: N: 56˚49'13.9" W: 118˚22'07.6"					
Slope (%)	N: 0		E: 2		S: 2		W: 0		
Slope (˚)	N: 0		E: 1		S: 1		W: 0		
Slope position (lower, mid, upper): mid-level (pretty level)					Aspect (facing & deg.) S Facing 168˚				
Elevation (m)	707								
Dominant tree species: Aw			Number of dominant trees: too many to count				Record DBH below		
Centre	8.7								
N	5.3								
E	7.2								
S	6.1								
W	7.2								
Site average	6.9								
Ground cover (%) in a 1m x 1m square:		lichen	moss	leaf litter	needles	bare soil	CWD/Twigs	Total Live	Total Shrubs
	N	0	Trace	100	0	0	0	40	15
	E	0	0	100	0	0	0	35	10
	S	0	Trace	100	0	0	0	25	5
	W	0	5	100	0	0	5	15	5
	Site Average	0	2.5	100	0	0	1.25	28.75	8.75
Sampling location distance to nearest tree (cm):	N	75	Notes: Young Aw falling down due to spring snofall						
	E	60							
	S	50							
	W	60							
	Site Average	61.25							

Plants	Common name	Latin name with authority
N	Grass spp.	*Poaceae spp.*
	Wild strawberry	*Fragaria virginiana* Duchesne
	Northern bedstraw	*Galium boreale* L.
	Bunchberry	*Cornus canadensis* L.
	Prickly rose	*Rosa acicularis* Lindl.
	Liliaceae spp.	*Lilium spp.*
E	Grass spp.	*Poaceae spp.*
	Northern bedstraw	*Galium boreale* L.
	Fireweed	*Chamerion angustifolium* (L.) Holu
	Bunchberry	*Cornus canadensis* L.
	Prickly rose	*Rosa acicularis* Lindl.
	Liliaceae spp.	*Lilium spp.*
	Wild red raspberry	*Rubus idaeus L.*
S	Grass spp.	*Poaceae spp.*
	Wild strawberry	*Fragaria virginiana* Duchesne
	Northern bedstraw	*Galium boreale* L.
	Lowbush cranberry	*Viburnum edule* (Michx.) Raf.
	Bunchberry	*Cornus canadensis* L.
	Prickly rose	*Rosa acicularis* Lindl.
	Meadow horsetail	*Equisetum pratense* Ehrh.
W	Grass spp.	*Poaceae spp.*
	Prickly rose	*Rosa acicularis* Lindl.
	Liliaceae spp.	*Lilium spp.*

EMEND Site & Soil Assessment

Site: 4A-Compt C: 892	Date: June 20, 16		GPS Coordinates: N: 56˚44'59.8" W: 118˚23'58.7"						
Slope (%)	N: 4		E: 4		S: 4		W: 9		
Slope (˚)	N: 2		E: 2		S: 2		W: 5		
Slope position (lower, mid, upper): mid					Aspect (facing & deg.) S/SW 220˚				
Elevation (m) 782									
Dominant tree species: aspen			Number of dominant trees: too many to count				Record DBH below		
Centre	7.7								
N	7.6								
E	6.6								
S	7.7								
W	3.7								
Site average	6.66								
Ground cover (%) in a 1m x 1m square:		lichen	moss	leaf litter	needles	bare soil	CWD/Twigs	Total Live	Total Shrubs
	N	0	0	100	0	0	0	15	5
	E	0	0	100	0	0	0	40	30
	S	0	0	100	0	0	0	25	5
	W	0	0	100	0	0	0	30	5
	Site Average	0	0	100	0	0	0	27.5	11.25
Sampling location distance to nearest tree (cm):	N	95							
	E	120							
	S	115							
	W	70							
	Site Average	100							

Plants	Common name	Latin name with authority
N	Wild strawberry	*Fragaria virginiana* Duchesne
	Fireweed	*Chamerion angustifolium* (L.) Holu
	Lowbush cranberry	*Viburnum edule* (Michx.) Raf.
	Prickly rose	*Rosa acicularis* Lindl.
	Twinflower	*Linnaea borealis* L.
	Canada violet	*Viola canadensis* L.
E	Palmate-leaved coltsfoot	*Petasites palmatus* (Ait.) Cronq.
	Northern bedstraw	*Galium boreale* L.
	Lowbush cranberry	*Viburnum edule* (Michx.) Raf.
	Prickly rose	*Rosa acicularis* Lindl.
	Liliaceae spp.	*Lilium spp.*
S	Palmate-leaved coltsfoot	*Petasites palmatus* (Ait.) Cronq.
	Grass spp.	*Poaceae spp.*
	Fireweed	*Chamerion angustifolium* (L.) Holu
	Lowbush cranberry	*Viburnum edule* (Michx.) Raf.
	Common Yarrow	*Achillea millefolium* L.
	Creamy peavine	*Lathyrus ochroleucus* Hook.
W	Palmate-leaved coltsfoot	*Petasites palmatus* (Ait.) Cronq.
	Grass spp.	*Poaceae spp.*
	Fireweed	*Chamerion angustifolium* (L.) Holu
	Prickly rose	*Rosa acicularis* Lindl.
	Liliaceae spp.	*Lilium spp.*
	Wild red raspberry	*Rubus idaeus L.*
	Sweet-scented bedstraw	*Galium triflorum* Michx.

EMEND Site & Soil Assessment									
Site: 4B-Compt C: 892		Date: June 20, 16		GPS Coordinates: N: 56.74940 W: 118.40495					
Slope (%)	N: 3		E: 4		S: 2		W: 1		
Slope (˚)	N: 2		E: 2.5		S: 1		W: 0.5		
Slope position (lower, mid, upper): upper					Aspect (facing & deg.) E / 100˚				
Elevation (m) 789									
Dominant tree species: aspen			Number of dominant trees: too many to count				Record DBH below		
Centre	7.8								
N	7.4								
E	7.6								
S	8.9								
W	10.5								
Site average	8.44								
Ground cover (%) in a 1m x 1m square:		lichen	moss	leaf litter	needles	bare soil	CWD/Twigs	Total Live	Total Shrubs
	N	0	0	100	0	0	0	40	10
	E	0	0	100	0	0	0	50	5
	S	0	0	100	0	0	5	25	5
	W	0	0	100	0	0	0	60	5
	Site Average	0	0	100	0	0	1.25	43.75	6.25
Sampling location distance to nearest tree (cm):	N	50	Notes: Aw are dying? (something eating leaves) Change of hydrology? Fen appears forming 20-50m E of site						
	E	60							
	S	50							
	W	55							
	Site Average	53.75							

Plants	Common name	Latin name with authority
N	Grass spp.	*Poaceae spp.*
	Wild strawberry	*Fragaria virginiana* Duchesne
	Fireweed	*Chamerion angustifolium* (L.) Holu
	Lowbush cranberry	*Viburnum edule* (Michx.) Raf.
	Bunchberry	*Cornus canadensis* L.
	Prickly rose	*Rosa acicularis* Lindl.
	Liliaceae spp.	*Lilium spp.*
	Creamy peavine	*Lathyrus ochroleucus* Hook.
	Wild red raspberry	*Rubus idaeus L.*
	Meadow horsetail	*Equisetum pratense* Ehrh.
E	Palmate-leaved coltsfoot	*Petasites palmatus* (Ait.) Cronq.
	Grass spp.	*Poaceae spp.*
	Fireweed	*Chamerion angustifolium* (L.) Holu
	Lowbush cranberry	*Viburnum edule* (Michx.) Raf.
	Bunchberry	*Cornus canadensis* L.
	Prickly rose	*Rosa acicularis* Lindl.
	Twinflower	*Linnaea borealis* L.
	Wild red raspberry	*Rubus idaeus L.*
	Meadow horsetail	*Equisetum pratense* Ehrh.
S	Palmate-leaved coltsfoot	*Petasites palmatus* (Ait.) Cronq.
	Fireweed	*Chamerion angustifolium* (L.) Holu
	Bunchberry	*Cornus canadensis* L.
	Prickly rose	*Rosa acicularis* Lindl.
	Twinflower	*Linnaea borealis* L.
	Creamy peavine	*Lathyrus ochroleucus* Hook.
	Wild red raspberry	*Rubus idaeus L.*
W	Palmate-leaved coltsfoot	*Petasites palmatus* (Ait.) Cronq.
	Wild Vetch	*Vicia americana* L.
	Fireweed	*Chamerion angustifolium* (L.) Holu
	Bunchberry	*Cornus canadensis* L.
	Twinflower	*Linnaea borealis* L.
	Common Yarrow	*Achillea millefolium* L.
	Wild red raspberry	*Rubus idaeus L.*
	Wild strawberry	*Fragaria virginiana* Duchesne
	Meadow horsetail	*Equisetum pratense* Ehrh.

EMEND Site & Soil Assessment				
Site: 4C-Compt C: 892	Date: June 20, 16	GPS Coordinates: N: 56˚44'59.2" W:118˚24'29.5"		
Slope (%)	N: 7	E: 5	S: 0	W: 4
Slope (˚)	N: 4	E: 3	S: 0	W: 2.5
Slope position (lower, mid, upper): mid		Aspect (facing & deg.) S/SE 158˚		
Elevation (m) 794				

Dominant tree species: Aw		Number of dominant trees: too many to count				Record DBH below			
Centre	8.40								
N	4.20								
E	4.70								
S	7.00								
W	8.20								
Site average	6.50								

Secondary tree species: Sw	Number of secondary trees: 4

Ground cover (%) in a 1m x 1m square:		lichen	moss	leaf litter	needles	bare soil	CWD/Twigs	Total Live	Total Shrubs
	N	0	0	100	0	0	0	50	40
	E	0	Trace	100	0	0	0	60	50
	S	0	Trace	100	0	0	0	20	5
	W	0	0	100	0	0	0	50	40
	Site Average	0	0	100	0	0	0	45	33.75

Sampling location distance to nearest tree (cm):		
	N	30
	E	94
	S	64
	W	80
	Site Average	67

Plants	Common name	Latin name with authority
N	Grass spp.	*Poaceae spp.*
	Fireweed	*Chamerion angustifolium* (L.) Holub
	Lowbush cranberry	*Viburnum edule* (Michx.) Raf.
	Bunchberry	*Cornus canadensis* L.
	Prickly rose	*Rosa acicularis* Lindl.
	Wild red raspberry	*Rubus idaeus L.*
E	Grass spp.	*Poaceae spp.*
	Lowbush cranberry	*Viburnum edule* (Michx.) Raf.
	Bunchberry	*Cornus canadensis* L.
	Asteraceae spp.	Unknown
	Palmate-leaved coltsfoot	*Petasites palmatus* (Ait.) Cronq.
	Wild red raspberry	*Rubus idaeus L.*
	Bishop's cap	*Mitella nuda* L.
S	Grass spp.	*Poaceae spp.*
	Wild strawberry	*Fragaria virginiana* Duchesne
	Lowbush cranberry	*Viburnum edule* (Michx.) Raf.
	Bunchberry	*Cornus canadensis* L.
	Wild red raspberry	*Rubus idaeus L.*
	Prickly rose	*Rosa acicularis* Lindl.
	Meadow horsetail	*Equisetum pratense* Ehrh.
W	Grass spp.	*Poaceae spp.*
	Lowbush cranberry	*Viburnum edule* (Michx.) Raf.
	Bunchberry	*Cornus canadensis* L.
	Prickly rose	*Rosa acicularis* Lindl.
	Wild red raspberry	*Rubus idaeus L.*

EMEND Site & Soil Assessment										
Site: 5A-Compt C: 892		Date: June 29, 16		GPS Coordinates: N: ˚56'56.3" W: 118˚24'27.0"						
Slope (%)	N: 2		E: 3		S: 3		W: 3			
Slope (˚)	N: 1		E: 1.5		S: 1.5		W: 1.5			
Slope position (lower, mid, upper): mid					Aspect (facing & deg.) SE 145˚					
Elevation (m) 781										
Dominant tree species: Aw			Number of dominant trees: 7				Record DBH below			
Centre	8.20									
N	5.50									
E	5.70									
S	9.20									
W	6.00									
Site average	6.92									
Secondary tree species: Pb			Number of secondary trees: 10							
Ground cover (%) in a 1m x 1m square:		lichen	moss	leaf litter	needles	bare soil	CWD/Twigs	Total Live	Total Shrubs	
	N	0	0	100	0	0	0	50	20	
	E	0	Trace	100	0	0	0	100	25	
	S	0	Trace	100	0	0	0	25	10	
	W	0	0	100	0	0	0	20	5	
	Site Average	0	0	100	0	0	0	48.75	15	
Sampling location distance to nearest tree (cm):	N	90 cm Aw, 40cm baby Sw								
	E	130 cm Pb								
	S	70 cm Aw								
	W	115 Pb								
	Site Average	101.25								

Plants	Common name	Latin name with authority
N	Palmate-leaved coltsfoot	*Petasites palmatus* (Ait.) Cronq.
	Grass spp.	*Poaceae spp.*
	Wild strawberry	*Fragaria virginiana* Duchesne
	Fireweed	*Chamerion angustifolium* (L.) Holu
	Lowbush cranberry	*Viburnum edule* (Michx.) Raf.
	Prickly rose	*Rosa acicularis* Lindl.
	Liliaceae spp.	*Lilium spp.*
	Creamy peavine	*Lathyrus ochroleucus* Hook.
	Bishop's cap	*Mitella nuda* L.
	Asteraceae spp.	Unknown
E	Grass spp.	*Poaceae spp.*
	Wild strawberry	*Fragaria virginiana* Duchesne
	Fireweed	*Chamerion angustifolium* (L.) Holu
	Lowbush cranberry	*Viburnum edule* (Michx.) Raf.
	Creamy peavine	*Lathyrus ochroleucus* Hook.
	Wintergreen spp.	*Pyrola spp.*
	Wild red raspberry	*Rubus idaeus L.*
S	Wild Vetch	*Vicia americana* L.
	Fireweed	*Chamerion angustifolium* (L.) Holu
	Lowbush cranberry	*Viburnum edule* (Michx.) Raf.
	Prickly rose	*Rosa acicularis* Lindl.
	Alder spp.	*Alnus spp.*
	Fireweed	*Chamerion angustifolium* (L.) Holu
W	Creamy peavine	*Lathyrus ochroleucus* Hook.
	Grass spp.	*Poaceae spp.*
	Fireweed	*Chamerion angustifolium* (L.) Holu
	Lowbush cranberry	*Viburnum edule* (Michx.) Raf.
	Bunchberry	*Cornus canadensis* L.
	Prickly rose	*Rosa acicularis* Lindl.
	Liliaceae spp.	*Lilium spp.*

EMEND Site & Soil Assessment

Site: 5B-Compt C: 892	Date: June 29, 16		GPS Coordinates: N: 56˚44'59.6" W: 118˚24'04.1"						
Slope (%)	N: 5		E:		S:		W:		
Slope (˚)	N: 3		E:		S:		W:		
Slope position (lower, mid, upper): mid					Aspect (facing & deg.) S / 186˚				
Elevation (m) 784									
Dominant tree species: Aw			Number of dominant trees:				Record DBH below		
Centre	9.3								
N	8.3								
E	6.7								
S	8.9								
W	6.4								
Site average	7.92								
Secondary tree species: Pb			Number of secondary trees: 4 young						
Ground cover (%) in a 1m x 1m square:		lichen	moss	leaf litter	needles	bare soil	CWD/Twigs	Total Live	Total Shrubs
	N	0	0	100	0	0	0	25	10
	E	0	0	100	0	0	0	50	20
	S	0	0	100	0	0	0	10	5
	W	0	0	100	0	0	0	60	30
	Site Average	0	0	100	0	0	0	36.25	16.25
Sampling location distance to nearest tree (cm):	N	70 cm Aw							
	E	85 cm Sw							
	S	40 cm Aw							
	W	60 cm Pb							
	Site Average	63.75							

Plants	Common name	Latin name with authority
N	Palmate-leaved coltsfoot	*Petasites palmatus* (Ait.) Cronq.
	Grass spp.	*Poaceae spp.*
	Fireweed	*Chamerion angustifolium* (L.) Holub
	Lowbush cranberry	*Viburnum edule* (Michx.) Raf.
	Prickly rose	*Rosa acicularis* Lindl.
E	Palmate-leaved coltsfoot	*Petasites palmatus* (Ait.) Cronq.
	Grass spp.	*Poaceae spp.*
	Fireweed	*Chamerion angustifolium* (L.) Holub
	Prickly rose	*Rosa acicularis* Lindl.
	Bunchberry	*Cornus canadensis* L.
	Canada buffaloberry	*Shepherdia canadensis* (L.) Nutt
S	Grass spp.	*Poaceae spp.*
	Wild strawberry	*Fragaria virginiana* Duchesne
	Prickly rose	*Rosa acicularis* Lindl.
	Liliaceae spp.	*Lilium spp.*
	Twinflower	*Linnaea borealis* L.
W	Grass spp.	*Poaceae spp.*
	Lowbush cranberry	*Viburnum edule* (Michx.) Raf.
	Prickly rose	*Rosa acicularis* Lindl.
	Liliaceae spp.	*Lilium spp.*
	Twinflower	*Linnaea borealis* L.
	Common Yarrow	*Achillea millefolium* L.
	Gooseberry	*Ribes* spp.

EMEND Site & Soil Assessment

Site: 5C-Compt C: 892	Date: June 29, 16		GPS Coordinates: N: 56.75036 W: 118.40070						
Slope (%)	N:		E:		S:		W:		
Slope (˚)	N:		E:		S:		W:		
Slope position (lower, mid, upper):					Aspect (facing & deg.)				
Elevation (m) 788									
Dominant tree species: Aw			Number of dominant trees:						
Ground cover (%) in a 1m x 1m square:		lichen	moss	leaf litter	needles	bare soil	CWD/Twigs	Total Live	Total Shrubs
	N	0	0	100	0	0	0	25	10
	E	0	0	100	0	0	0	10	Trace
	S	0	0	100	0	0	0	70	20
	W								
	Site Average	0	0	100	0	0	0	35	15
Sampling location distance to nearest tree (cm):	N	70							
	E	60							
	S	70							
	W								
	Site Average	66.66667							

Plants	Common name	Latin name with authority
N	Palmate-leaved coltsfoot	*Petasites palmatus* (Ait.) Cronq.
	Grass spp.	*Poaceae spp.*
	Fireweed	*Chamerion angustifolium* (L.) Holub
	Bunchberry	*Cornus canadensis* L.
	Prickly rose	*Rosa acicularis* Lindl.
	Twinflower	*Linnaea borealis* L.
E	Palmate-leaved coltsfoot	*Petasites palmatus* (Ait.) Cronq.
	Grass spp.	*Poaceae spp.*
	Fireweed	*Chamerion angustifolium* (L.) Holub
	Lowbush cranberry	*Viburnum edule* (Michx.) Raf.
	Wild red raspberry	*Rubus idaeus L.*
S	Palmate-leaved coltsfoot	*Petasites palmatus* (Ait.) Cronq.
	Grass spp.	*Poaceae spp.*
	Prickly rose	*Rosa acicularis* Lindl.
	Wild red raspberry	*Rubus idaeus L.*
	Gooseberry	*Ribes* spp.

EMEND Site & Soil Assessment

Site: 6A-Compt C: 880		Date: June 25, 16		GPS Coordinates: N: 56.75058 W: 118.39248					
Slope (%)	N: 7		E: 5		S: 7		W: 6		
Slope (˚)	N: 4		E: 3		S: 4		W: 3.5		
Slope position (lower, mid, upper):					Aspect (facing & deg.) SE Facing 148˚				
Elevation (m) 779									
Dominant tree species: Aw			Number of dominant trees:				Record DBH below		
Centre	6.7								
N	3.2								
E	6.4								
S	5.9								
W	4.8								
Site average	5.4								
Ground cover (%) in a 1m x 1m square:		lichen	moss	leaf litter	needles	bare soil	CWD/Twigs	Total Live	Total Shrubs
	N	0	0	100	0	0	0	90	25
	E	0	0	100	0	0	0	80	20
	S	0	0	100	0	0	0	85	35
	W	0	0	100	0	0	0	25	10
	Site Average	0	0	100	0	0	0	70	22.5
Sampling location distance to nearest tree (cm):	N	70 cm Pb							
	E	70 cm Aw							
	S	45 cm							
	W	85 cm							
	Site Average	67.5							

Plants	Common name	Latin name with authority
N	Palmate-leaved coltsfoot	*Petasites palmatus* (Ait.) Cronq.
	Grass spp.	*Poaceae spp.*
	Wild strawberry	*Fragaria virginiana* Duchesne
	Fireweed	*Chamerion angustifolium* (L.) Holub
	Bunchberry	*Cornus canadensis* L.
	Wild red raspberry	*Rubus idaeus L.*
	Bishop's cap	*Mitella nuda* L.
	Arrow-leaved coltsfoot	*Petasites sagittatus* Pursh.
E	Palmate-leaved coltsfoot	*Petasites palmatus* (Ait.) Cronq.
	Grass spp.	*Poaceae spp.*
	Common Dandelion	*Taraxacum officinale* (L.) Weber ex F.H. Wigg
	Wild strawberry	*Fragaria virginiana* Duchesne
	Fireweed	*Chamerion angustifolium* (L.) Holub
	Bunchberry	*Cornus canadensis* L.
	Twinflower	*Linnaea borealis* L.
	Creamy peavine	*Lathyrus ochroleucus* Hook.
	Wild red raspberry	*Rubus idaeus L.*
	Bishop's cap	*Mitella nuda* L.
	Meadow horsetail	*Equisetum pratense* Ehrh.
	Arrow-leaved coltsfoot	*Petasites sagittatus* Pursh.
S	Grass spp.	*Poaceae spp.*
	Wild strawberry	*Fragaria virginiana* Duchesne
	Wild Vetch	*Vicia americana* L.
	Fireweed	*Chamerion angustifolium* (L.) Holub
	Bunchberry	*Cornus canadensis* L.
	Prickly rose	*Rosa acicularis* Lindl.
	Creamy peavine	*Lathyrus ochroleucus* Hook.
	Wintergreen spp.	*Pyrola spp.*
	Wild red raspberry	*Rubus idaeus L.*
	Bishop's cap	*Mitella nuda* L.
	Canada buffaloberry	*Shepherdia canadensis* (L.) Nutt
	Arrow-leaved coltsfoot	*Petasites sagittatus* Pursh.
W	Grass spp.	*Poaceae spp.*
	Wild strawberry	*Fragaria virginiana* Duchesne
	Bunchberry	*Cornus canadensis* L.
	Prickly rose	*Rosa acicularis* Lindl.
	Twinflower	*Linnaea borealis* L.
	Creamy peavine	*Lathyrus ochroleucus* Hook.
	Wintergreen spp.	*Pyrola spp.*
	Wild red raspberry	*Rubus idaeus L.*

EMEND Site & Soil Assessment									
Site: 6B-Compt C: 892	Date: June 25, 16		GPS Coordinates: N: 56.75029 W: 118.39866						
Slope (%)	N: 5		E:		S:		W:		
Slope (˚)	N: 3		E:		S:		W:		
Slope position (lower, mid, upper):					Aspect (facing & deg.) SE / 134˚				
Elevation (m)	785								
Dominant tree species: Aw			Number of dominant trees:				Record DBH below		
Centre	8								
N	6.8								
E	6.7								
S	7.9								
W	8.3								
Site average	7.54								
Ground cover (%) in a 1m x 1m square:		lichen	moss	leaf litter	needles	bare soil	CWD/Twigs	Total Live	Total Shrubs
	N	0	0	100	0	0	0	75	10
	E	0	Trace	100	0	0	0	25	5
	S	0	3	100	0	0	25	15	0
	W	0	0	100	0	0	0	50	45
	Site Average	0	1	100	0	0	6.25	41.25	15
Sampling location distance to nearest tree (cm):	N	160	Notes: some site info not recorded because we had to leave due to lightning						
	E	90							
	S	180							
	W								
	Site Average	143.3							

Plants	Common name	Latin name with authority
N	Fireweed	*Chamerion angustifolium* (L.) Holub
	Bunchberry	*Cornus canadensis* L.
	Prickly rose	*Rosa acicularis* Lindl.
	Twinflower	*Linnaea borealis* L.
	Wild red raspberry	*Rubus idaeus L.*
	Bishop's cap	*Mitella nuda* L.
	Baby Pb	*Betula spp.*
E	Grass spp.	*Poaceae spp.*
	Prickly rose	*Rosa acicularis* Lindl.
	Liliaceae spp.	*Lilium spp.*
	Bishop's cap	*Mitella nuda* L.
	Meadow horsetail	*Equisetum pratense* Ehrh.
	Wild Sarsaparilla	*Aralia nudicaulis* L.
	Cow parsnip	*Heracleum maximum* Bartram
S	Grass spp.	*Poaceae spp.*
	Twinflower	*Linnaea borealis* L.
	Asteraceae spp.	*Unknown*
	Bishop's cap	*Mitella nuda* L.
	Common horsetail	*Equisetum arvense* L.
	Arrow-leaved coltsfoot	*Petasites sagittatus* Pursh.
	Wild Sarsaparilla	*Aralia nudicaulis* L.
W	Grass spp.	*Poaceae spp.*
	Wild Vetch	*Vicia americana* L.
	Fireweed	*Chamerion angustifolium* (L.) Holub
	Lowbush cranberry	*Viburnum edule* (Michx.) Raf.
	Prickly rose	*Rosa acicularis* Lindl.
	Wild red raspberry	*Rubus idaeus L.*

EMEND Site & Soil Assessment									
Site: 6C-Compt C: 892		Date: June 25, 16		GPS Coordinates: N: 56.74999 W: 118.39799					
Slope (%)	N: 5		E: 8		S: 8		W: 5		
Slope (˚)	N: 3		E: 9.5		S: 9.5		W: 3		
Slope position (lower, mid, upper):					Aspect (facing & deg.) SE / 152˚				
Elevation (m)	785								
Dominant tree species:			Number of dominant trees:				Record DBH below		
Centre	8.3								
N	5.5								
E	7.9								
S	7.4								
W	5.5								
Site average	6.92								
Secondary tree species:		Sw	Number of secondary trees: Sw 5 babies						
Ground		lichen	moss	leaf litter	needles	bare soil	CWD/Twigs	Total Live	Total Shrubs
cover (%) ir	N	0	0	100	0	0	0	75	10
a 1m x 1m	E	0	0	40	0	0	0	25	5
square:	S	0	0	100	0	0	0	40	15
	W	0	0	100	0	0	10	70	20
	Site Average	0	0	85	0	0	2.5	52.5	12.5
Sampling	N	40							
location	E	45							
distance to	S	50							
nearest tre	W	60							
(cm):	Site Average	48.75							

Plants	**Common name**	**Latin name with authority**
N	Fireweed	*Chamerion angustifolium* (L.) Holu
	Bunchberry	*Cornus canadensis* L.
	Prickly rose	*Rosa acicularis* Lindl.
	Liliaceae spp.	*Lilium spp.*
	Wintergreen spp.	*Pyrola spp.*
	Wild red raspberry	*Rubus idaeus L.*
	Gooseberry	*Ribes* spp.
E	Grass spp.	*Poaceae spp.*
	Fireweed	*Chamerion angustifolium* (L.) Holu
	Lowbush cranberry	*Viburnum edule* (Michx.) Raf.
	Prickly rose	*Rosa acicularis* Lindl.
	Creamy peavine	*Lathyrus ochroleucus* Hook.
	Common horsetail	*Equisetum arvense* L.
S	Grass spp.	*Poaceae spp.*
	Fireweed	*Chamerion angustifolium* (L.) Holu
	Prickly rose	*Rosa acicularis* Lindl.
	Liliaceae spp.	*Lilium spp.*
	Twinflower	*Linnaea borealis* L.
	Wintergreen spp.	*Pyrola spp.*
	Wild red raspberry	*Rubus idaeus L.*
W	Grass spp.	*Poaceae spp.*
	Wild strawberry	*Fragaria virginiana* Duchesne
	Fireweed	*Chamerion angustifolium* (L.) Holu
	Lowbush cranberry	*Viburnum edule* (Michx.) Raf.
	Prickly rose	*Rosa acicularis* Lindl.
	Liliaceae spp.	*Lilium spp.*
	Twinflower	*Linnaea borealis* L.
	Wintergreen spp.	*Pyrola spp.*
	Wild red raspberry	*Rubus idaeus L.*

EMEND Site & Soil Assessment									
Site: 7A-Compt A: 852		Date: June 19, 16		GPS Coordinates: N: 56.75147 W: 118.32588					
Slope (%)	N: 13		E: 15		S: 8		W: 8		
Slope (˚)	N: 7		E: 8.5		S: 4.5		W: 4.5		
Slope position (lower, mid, upper): mid					Aspect (facing & deg.) NE/N 72˚				
Elevation (m)	779								
Dominant tree species:			Number of dominant trees: 5				Record DBH below		
Centre	30.3								
N	29.2								
E	28.2								
S	23.6								
W	25								
Site average	27.26								
Ground cover (%) in a 1m x 1m square:		lichen	moss	leaf litter	needles	bare soil	CWD/Twigs	Total Live	Total Shrubs
	N	0	Trace	100	0	0	0	95	5
	E	0	2	85	0	0	15	50	15
	S	0	Trace	100	0	0	15	40	10
	W	0	0	100	0	0	0	50	15
	Site Average	0	1	96.25	0	0	7.5	58.75	11.25
Sampling location distance to nearest tree (cm):	N	120							
	E								
	S								
	W								
	Site Average	120							

Plants	Common name	Latin name with authority
N	Fireweed	*Chamerion angustifolium* (L.) Holu
	Lowbush cranberry	*Viburnum edule* (Michx.) Raf.
	Bunchberry	*Cornus canadensis* L.
	Prickly rose	*Rosa acicularis* Lindl.
	Arrow-leaved coltsfoot	*Petasites sagittatus* Pursh.
	Wild Sarsaparilla	*Aralia nudicaulis* L.
	Moss spp.	Unknown
E	Lowbush cranberry	*Viburnum edule* (Michx.) Raf.
	Bunchberry	*Cornus canadensis* L.
	Prickly rose	*Rosa acicularis* Lindl.
	Grass spp.	*Poaceae spp.*
	Wintergreen spp.	*Pyrola spp.*
	Wild Sarsaparilla	*Aralia nudicaulis* L.
	Moss spp.	Unknown
S	Wild strawberry	*Fragaria virginiana* Duchesne
	Fireweed	*Chamerion angustifolium* (L.) Holu
	Lowbush cranberry	*Viburnum edule* (Michx.) Raf.
	Bunchberry	*Cornus canadensis* L.
	Prickly rose	*Rosa acicularis* Lindl.
	Creamy peavine	*Lathyrus ochroleucus* Hook.
	Wintergreen spp.	*Pyrola spp.*
	Wild Sarsaparilla	*Aralia nudicaulis* L.
W	Fireweed	*Chamerion angustifolium* (L.) Holu
	Lowbush cranberry	*Viburnum edule* (Michx.) Raf.
	Bunchberry	*Cornus canadensis* L.
	Prickly rose	*Rosa acicularis* Lindl.
	Liliaceae spp.	*Lilium spp.*
	Twinflower	*Linnaea borealis* L.
	Wintergreen spp.	*Pyrola spp.*
	Arrow-leaved coltsfoot	*Petasites sagittatus* Pursh.
	Wild Sarsaparilla	*Aralia nudicaulis* L.

EMEND Site & Soil Assessment

Site: 7B-Compt A: 852		Date: June 19, 16		GPS Coordinates: N: 56.75185 W: 118.32731					
Slope (%)	N: 5		E: 4		S: 2		W: 5		
Slope (˚)	N: 3		E: 2		S: 1		W: 3		
Slope position (lower, mid, upper): mid-upper					Aspect (facing & deg.) N / 2˚				
Elevation (m) 780									
Dominant tree species: Aw			Number of dominant trees: 8				Record DBH below		
Centre	28.6								
N	20								
E	27.3								
S	30.7								
W	32.8								
Site average	27.88								
Ground cover (%) in a 1m x 1m square:		lichen	moss	leaf litter	needles	bare soil	CWD/Twigs	Total Live	Total Shrubs
	N	Trace	Trace	100	0	0	5	80	20
	E	0	Trace	100	0	0	0	70	30
	S	0	0	100	0	0	10	90	45
	W	0	0	100	0	0	15	90	60
	Site Average	0	0	100	0	0	7.5	82.5	38.75
Sampling location distance to nearest tree (cm):	N	80							
	E	230							
	S	60							
	W								
	Site Average	123.3333							

Plants	Common name	Latin name with authority
N	Palmate-leaved coltsfoot	*Petasites palmatus* (Ait.) Cronq.
	Northern bedstraw	*Galium boreale* L.
	Fireweed	*Chamerion angustifolium* (L.) Holub
	Bunchberry	*Cornus canadensis* L.
	Prickly rose	*Rosa acicularis* Lindl.
	Twinflower	*Linnaea borealis* L.
	Creamy peavine	*Lathyrus ochroleucus* Hook.
	Pink wintergreen	*Pyrola asarifolia* Michx.
	Arrow-leaved coltsfoot	*Petasites sagittatus* Pursh.
	Moss spp.	Unknown
	Lichen spp.	*Unknown*
E	Palmate-leaved coltsfoot	*Petasites palmatus* (Ait.) Cronq.
	Wild strawberry	*Fragaria virginiana* Duchesne
	Northern bedstraw	*Galium boreale* L.
	Fireweed	*Chamerion angustifolium* (L.) Holub
	Lowbush cranberry	*Viburnum edule* (Michx.) Raf.
	Bunchberry	*Cornus canadensis* L.
	Prickly rose	*Rosa acicularis* Lindl.
	Twinflower	*Linnaea borealis* L.
	Creamy peavine	*Lathyrus ochroleucus* Hook.
	Wintergreen spp.	*Pyrola spp.*
	Moss spp.	Unknown
S	Palmate-leaved coltsfoot	*Petasites palmatus* (Ait.) Cronq.
	Fireweed	*Chamerion angustifolium* (L.) Holub
	Lowbush cranberry	*Viburnum edule* (Michx.) Raf.
	Bunchberry	*Cornus canadensis* L.
	Prickly rose	*Rosa acicularis* Lindl.
	Liliaceae spp.	*Lilium spp.*
	Twinflower	*Linnaea borealis* L.
	Bishop's cap	*Mitella nuda* L.
	Canada buffaloberry	*Shepherdia canadensis* (L.) Nutt
W	Grass spp.	*Poaceae spp.*
	Fireweed	*Chamerion angustifolium* (L.) Holub
	Lowbush cranberry	*Viburnum edule* (Michx.) Raf.
	Bunchberry	*Cornus canadensis* L.
	Prickly rose	*Rosa acicularis* Lindl.
	Liliaceae spp.	*Lilium spp.*

EMEND Site & Soil Assessment

Site: 7C-Compt A: 852	Date: June 18, 16	GPS Coordinates: N: 56.75177 W: 118.32803		
Slope (%)	N: 5	E: 0	S: 4	W: 4
Slope (˚)	N: 3	E: 0	S: 2.5	W: 2.5
Slope position (lower, mid, upper): mid-upper			Aspect (facing & deg.) NE Facing 22˚	
Elevation (m) 778				

Dominant tree species:		Number of dominant trees:				Record DBH below			
Centre	24.9								
N	22.9								
E	19.5								
S	28								
W	16								
Site average	22.26								

Ground cover (%) in a 1m x 1m square:		lichen	moss	leaf litter	needles	bare soil	CWD/Twigs	Total Live	Total Shrubs
	N	0	0	100	0	0	0	80	10
	E	0	Trace	0	0	0	0	80	10
	S	0	Trace	100	0	0	0	25	10
	W	0	15	0	0	0	0	50	40
	Site Average	0	7.5	50	0	0	0	58.75	17.5

Sampling location distance to nearest tree (cm):			
	N	110	Notes: Alder present = high moisture
	E	125	
	S	160	
	W	163	
	Site Average	139.5	

Plants	Common name	Latin name with authority
N	Palmate-leaved coltsfoot	*Petasites palmatus* (Ait.) Cronq.
	Bunchberry	*Cornus canadensis* L.
	Prickly rose	*Rosa acicularis* Lindl.
	Twinflower	*Linnaea borealis* L.
	Veiny pea	*Lathyrus venosus* Muhl.
	Arrow-leaved coltsfoot	*Petasites sagittatus* Pursh.
	Creamy peavine	*Lathyrus ochroleucus* Hook.
	Palmate-leaved coltsfoot	*Petasites palmatus* (Ait.) Cronq.
E	Bunchberry	*Cornus canadensis* L.
	Prickly rose	*Rosa acicularis* Lindl.
	Twinflower	*Linnaea borealis* L.
	Creamy peavine	*Lathyrus ochroleucus* Hook.
	Moss spp.	Unknown
	Baby Aw	*Populus spp.*
	Red and white baneberry	*Actaea rubra* (Ait.) Willd.
S	Palmate-leaved coltsfoot	*Petasites palmatus* (Ait.) Cronq.
	Bunchberry	*Cornus canadensis* L.
	Prickly rose	*Rosa acicularis* Lindl.
	Twinflower	*Linnaea borealis* L.
	Creamy peavine	*Lathyrus ochroleucus* Hook.
	Wintergreen spp.	*Pyrola spp.*
	Canada buffaloberry	*Shepherdia canadensis* (L.) Nutt
	Moss spp.	Unknown
W	Bunchberry	*Cornus canadensis* L.
	Prickly rose	*Rosa acicularis* Lindl.
	Liliaceae spp.	*Lilium spp.*
	Twinflower	*Linnaea borealis* L.
	Moss spp.	Unknown

EMEND Site & Soil Assessment									
Site: 8A-Compt B: 862	Date: June 22, 16		GPS Coordinates: N: 56.74729 W: 118.36064						
Slope (%)	N: 7		E: 5		S: 2		W: 12		
Slope (˚)	N: 4		E: 3		S: 1		W: 7		
Slope position (lower, mid, upper): Upper					Aspect (facing & deg.) SW Facing 232˚				
Elevation (m) 854									
Dominant tree species: Aw			Number of dominant trees: 5				Record DBH below		
Sarah's Tree	27.8								
N	25.7								
E	24.2								
S	26.4								
W	18.8								
Site average	24.58								
Secondary tree species: Sw			Number of secondary trees: 3 Sw trees on outskirts of plot. Quite large.						

Ground cover (%) in a 1m x 1m square:		lichen	moss	leaf litter	needles	bare soil	CWD/Twigs	Total Live	Total Shrubs
	N	0	5	100	0	0	0	85	40
	E	0	0	100	0	0	0	50	15
	S	0	0	100	0	0	0	90	10
	W	0	0	100	0	0	0	30	5
	Site Average	0	1.25	100	0	0	0	63.75	17.5

Sampling location distance to nearest tree (cm):		
	N	145
	E	170
	S	140
	W	100
	Site Average	138.75

Plants	**Common name**	**Latin name with authority**
N	Grass spp.	*Poaceae spp.*
	Northern bedstraw	*Galium boreale* L.
	Fireweed	*Chamerion angustifolium* (L.) Holub
	Lowbush cranberry	*Viburnum edule* (Michx.) Raf.
	Bunchberry	*Cornus canadensis* L.
	Prickly rose	*Rosa acicularis* Lindl.
	Twinflower	*Linnaea borealis* L.
	Canada buffaloberry	*Shepherdia canadensis* (L.) Nutt
	Moss spp.	Unknown
	Wild lily-of-the-valley	*Maianthemum canadensis* Desf.
E	Grass spp.	*Poaceae spp.*
	Northern bedstraw	*Galium boreale* L.
	Fireweed	*Chamerion angustifolium* (L.) Holub
	Lowbush cranberry	*Viburnum edule* (Michx.) Raf.
	Wild red raspberry	*Rubus idaeus L.*
	Bunchberry	*Cornus canadensis* L.
	Creamy peavine	*Lathyrus ochroleucus* Hook.
	Wintergreen spp.	*Pyrola spp.*
S	Grass spp.	*Poaceae spp.*
	Lowbush cranberry	*Viburnum edule* (Michx.) Raf.
	Bunchberry	*Cornus canadensis* L.
	Prickly rose	*Rosa acicularis* Lindl.
	Twinflower	*Linnaea borealis* L.
	Wild Vetch	*Vicia americana* L.
W	Grass spp.	*Poaceae spp.*
	Northern bedstraw	*Galium boreale* L.
	Fireweed	*Chamerion angustifolium* (L.) Holub
	Bunchberry	*Cornus canadensis* L.
	Prickly rose	*Rosa acicularis* Lindl.
	Twinflower	*Linnaea borealis* L.
	Creamy peavine	*Lathyrus ochroleucus* Hook.
	Wintergreen spp.	*Pyrola spp.*
	Arrow-leaved coltsfoot	*Petasites sagittatus* Pursh.

EMEND Site & Soil Assessment									
Site: 8B-Compt: 862		Date: June 21, 16		GPS Coordinates: N: 56.74726 W: 118.36147					
Slope (%)	N: 10		E: 7		S: 11		W: 14		
Slope (˚)	N: 6		E: 4		S: 6		W: 8		
Slope position (lower, mid, upper): Upper-Mid					Aspect (facing & deg.) SW 253˚				
Elevation (m) 860									
Dominant tree species: Aw			Number of dominant trees: 13				Record DBH below		
Centre	24.5								
N	25.4								
E	23.7								
S	30								
W	21.6								
Site average	25.04								
Ground cover (%) in a 1m x 1m square:		lichen	moss	leaf litter	needles	bare soil	CWD/Twigs	Total Live	Total Shrubs
	N	0	0	100	0	0	8	25	15
	E	0	0	100	0	0	5	40	20
	S	0	0	100	0	0	0	40	15
	W	0	0	100	0	0	5	75	10
	Site Average	0	0	100	0	0	4.5	45	15
Sampling location distance to nearest tree (cm):	N	125	Notes: Lots of alder = high moisture						
	E	115							
	S	150							
	W	150							
	Site Average	135							

Plants	Common name	Latin name with authority	
N	Fireweed	*Chamerion angustifolium*	(L.) Holub
	Lowbush cranberry	*Viburnum edule*	(Michx.) Raf.
	Bunchberry	*Cornus canadensis*	L.
	Wintergreen spp.	*Pyrola spp.*	
E	Grass spp.	*Poaceae spp.*	
	Fireweed	*Chamerion angustifolium*	(L.) Holub
	Lowbush cranberry	*Viburnum edule*	(Michx.) Raf.
	Bunchberry	*Cornus canadensis*	L.
	Twinflower	*Linnaea borealis*	L.
	Creamy peavine	*Lathyrus ochroleucus*	Hook.
	Wintergreen spp.	*Pyrola spp.*	
S	Palmate-leaved coltsfoot	*Petasites palmatus*	(Ait.) Cronq.
	Lowbush cranberry	*Viburnum edule*	(Michx.) Raf.
	Bunchberry	*Cornus canadensis*	L.
	Prickly rose	*Rosa acicularis*	Lindl.
	Creamy peavine	*Lathyrus ochroleucus*	Hook.
	Wintergreen spp.	*Pyrola spp.*	
	Wild red raspberry	*Rubus idaeus L.*	
	Canada buffaloberry	*Shepherdia canadensis*	(L.) Nutt
W	Palmate-leaved coltsfoot	*Petasites palmatus*	(Ait.) Cronq.
	Grass spp.	*Poaceae spp.*	
	Fireweed	*Chamerion angustifolium*	(L.) Holub
	Bunchberry	*Cornus canadensis*	L.
	Creamy peavine	*Lathyrus ochroleucus*	Hook.
	Wintergreen spp.	*Pyrola spp.*	
	Canada buffaloberry	*Shepherdia canadensis*	(L.) Nutt

EMEND Site & Soil Assessment									
Site: 8C-Compt B: 862		Date: June 21, 16		GPS Coordinates: N: 56.74589 W: 118.36186					
Slope (%)	N: 7		E: 2		S: 9		W: 14		
Slope (˚)	N: 4		E: 1		S: 5		W: 8		
Slope position (lower, mid, upper): Upper					Aspect (facing & deg.) W/NW 300˚				
Elevation (m)	859								
Dominant tree species: Aw			Number of dominant trees: 10				Record DBH below		
Centre	33.8								
N	18.3								
E	23.4								
S	17.5								
W	16.3								
Site average	21.86								
Ground cover (%) in a 1m x 1m square:		lichen	moss	leaf litter	needles	bare soil	CWD/Twigs	Total Live	Total Shrubs
	N	0	0	100	0	0	0	85	25
	E	0	Trace	95	0	0	5	60	50
	S	0	0	100	0	0	0	75	15
	W	0	Trace	100	0	0	Trace	60	20
	Site Average	0	0	98.75	0	0	1.67	70	27.5
Sampling location distance to nearest tree (cm):	N	85							
	E	115							
	S	61							
	W	90							
	Site Average	87.75							

Plants	Common name	Latin name with authority
N	Palmate-leaved coltsfoot	*Petasites palmatus* (Ait.) Cronq.
	Grass spp.	*Poaceae spp.*
	Fireweed	*Chamerion angustifolium* (L.) Holub
	Lowbush cranberry	*Viburnum edule* (Michx.) Raf.
	Bunchberry	*Cornus canadensis* L.
	Creamy peavine	*Lathyrus ochroleucus* Hook.
	Wild red raspberry	*Rubus idaeus L.*
	Canada buffaloberry	*Shepherdia canadensis* (L.) Nutt
	Arrow-leaved coltsfoot	*Petasites sagittatus* Pursh.
E	Grass spp.	*Poaceae spp.*
	Lowbush cranberry	*Viburnum edule* (Michx.) Raf.
	Bunchberry	*Cornus canadensis* L.
	Creamy peavine	*Lathyrus ochroleucus* Hook.
	Moss spp.	Unknown
S	Palmate-leaved coltsfoot	*Petasites palmatus* (Ait.) Cronq.
	Fireweed	*Chamerion angustifolium* (L.) Holub
	Lowbush cranberry	*Viburnum edule* (Michx.) Raf.
	Bunchberry	*Cornus canadensis* L.
	Twinflower	*Linnaea borealis* L.
	Wintergreen spp.	*Pyrola spp.*
	Wild red raspberry	*Rubus idaeus L.*
	Baby Aw	*Populus spp.*
	Canada buffaloberry	*Shepherdia canadensis* (L.) Nutt
W	Grass spp.	*Poaceae spp.*
	Wild strawberry	*Fragaria virginiana* Duchesne
	Northern bedstraw	*Galium boreale* L.
	Fireweed	*Chamerion angustifolium* (L.) Holub
	Lowbush cranberry	*Viburnum edule* (Michx.) Raf.
	Bunchberry	*Cornus canadensis* L.
	Prickly rose	*Rosa acicularis* Lindl.
	Twinflower	*Linnaea borealis* L.
	Creamy peavine	*Lathyrus ochroleucus* Hook.
	Canada buffaloberry	*Shepherdia canadensis* (L.) Nutt
	Moss spp.	Unknown
	Wild lily-of-the-valley	*Maianthemum canadensis* Desf.

EMEND Site & Soil Assessment									
Site: 9A-Compt I: 940		Date: June 27, 16	GPS Coordinates: N: 56˚49'07.6" W: 118˚21'32.5"						
Slope (%)	N: 1		E: 3		S: 6		W: 2		
Slope (˚)	N: 0.5		E: 1.5		S: 3.5		W: 0.5		
Slope position (lower, mid, upper): Mid					Aspect (facing & deg.) SE / 132˚				
Elevation (m)	698								
Dominant tree species: Aw			Number of dominant trees: >20 young Aw, 10 mature Aw				Record DBH below		
Centre	33								
N	32.2								
E	29.8								
S	32.5								
W	34.6								
Site average	32.42								
Secondary tree species:		Sw	Number of secondary trees: 1 young Sw						
Ground cover (%) in a 1m x 1m square:		lichen	moss	leaf litter	needles	bare soil	CWD/Twigs	Total Live	Total Shrubs
	N	Trace	0	100	0	0	0	40	5
	E	0	5	100	0	0	0	60	10
	S	0	0	100	0	0	0	100	10
	W	0	0	100	0	0	5	85	8
	Site Average	0	1.25	100	0	0	1.25	71.25	8.25
Sampling location distance to nearest tree (cm):	N	160							
	E	165							
	S	210							
	W	80							
	Site Average	153.75							

Plants	Common name	Latin name with authority
N	Palmate-leaved coltsfoot	*Petasites palmatus* (Ait.) Cronq.
	Grass spp.	*Poaceae spp.*
	Wild strawberry	*Fragaria virginiana* Duchesne
	Northern bedstraw	*Galium boreale* L.
	Fireweed	*Chamerion angustifolium* (L.) Holub
	Bunchberry	*Cornus canadensis* L.
	Twinflower	*Linnaea borealis* L.
	Liliaceae spp.	*Lilium spp.*
	Wild red raspberry	*Rubus idaeus L.*
	Stair-step moss	*Hylocomium splendens* Hedw.
E	Grass spp.	*Poaceae spp.*
	Wild Vetch	*Vicia americana* L.
	Northern bedstraw	*Galium boreale* L.
	Fireweed	*Chamerion angustifolium* (L.) Holub
	Bunchberry	*Cornus canadensis* L.
	Prickly rose	*Rosa acicularis* Lindl.
	Twinflower	*Linnaea borealis* L.
	Creamy peavine	*Lathyrus ochroleucus* Hook.
	Wintergreen spp.	*Pyrola spp.*
	Arrow-leaved coltsfoot	*Petasites sagittatus* Pursh.
	Electric eel	*Dicranum polysetum* Sw.
S	Palmate-leaved coltsfoot	*Petasites palmatus* (Ait.) Cronq.
	Grass spp.	*Poaceae spp.*
	Wild strawberry	*Fragaria virginiana* Duchesne
	Wild Vetch	*Vicia americana* L.
	Northern bedstraw	*Galium boreale* L.
	Fireweed	*Chamerion angustifolium* (L.) Holub
	Bunchberry	*Cornus canadensis* L.
	Prickly rose	*Rosa acicularis* Lindl.
	Creamy peavine	*Lathyrus ochroleucus* Hook.
	Arrow-leaved coltsfoot	*Petasites sagittatus* Pursh.
	Veiny meadow-rue	*Thalictrum venulosum* Trel.
W	Arrow-leaved coltsfoot	*Petasites sagittatus* Pursh.
	Northern bedstraw	*Galium boreale* L.
	Fireweed	*Chamerion angustifolium* (L.) Holub
	Bunchberry	*Cornus canadensis* L.
	Grass spp.	*Poaceae spp.*
	Prickly rose	*Rosa acicularis* Lindl.
	Creamy peavine	*Lathyrus ochroleucus* Hook.
	Bishop's cap	*Mitella nuda* L.

EMEND Site & Soil Assessment

Site: 9B-Compt I: 940		Date: June 27, 16		GPS Coordinates: N: 56˚49'07.1" W: 118˚21'46.7"					
Slope (%)	N: 4		E: 3		S: 3		W: 2		
Slope (˚)	N: 2.5		E: 2		S: 2		W: 0.5		
Slope position (lower, mid, upper):					Aspect (facing & deg.)				
Elevation (m)	705								
Dominant tree species: Aw			Number of dominant trees: 10				Record DBH below		
Centre	40.5								
N	37.4								
E	31.7								
S	29.1								
W	45								
Site average	36.74								
Secondary tree species: Sw			Number of secondary trees:				Record DBH Below		
Ground cover (%) in a 1m x 1m square:		lichen	moss	leaf litter	needles	bare soil	CWD/Twigs	Total Live	Total Shrubs
	N	0	10	90	0	0	0	90	0
	E	0	10	90	0	0	0	60	10
	S	0	Trace	100	0	0	0	90	5
	W	0	0	80	0	0	0	80	25
	Site Average	0	6.6666667	90	0	0	0	80	10
Sampling location distance to nearest tree (cm):	N	370	Notes: Bog birch present = moisture						
	E	165							
	S	170							
	W	140							
	Site Average	211.25							

Plants	Common name	Latin name with authority
N	Palmate-leaved coltsfoot	*Petasites palmatus* (Ait.) Cronq.
	Grass spp.	*Poaceae spp.*
	Wild strawberry	*Fragaria virginiana* Duchesne
	Northern bedstraw	*Galium boreale* L.
	Fireweed	*Chamerion angustifolium* (L.) Holub
	Bunchberry	*Cornus canadensis* L.
	Creamy peavine	*Lathyrus ochroleucus* Hook.
	Veiny meadow-rue	*Thalictrum venulosum* Trel.
	Stair-step moss	*Hylocomium splendens* Hedw.
E	Palmate-leaved coltsfoot	*Petasites palmatus* (Ait.) Cronq.
	Grass spp.	*Poaceae spp.*
	Wild strawberry	*Fragaria virginiana* Duchesne
	Northern bedstraw	*Galium boreale* L.
	Bunchberry	*Cornus canadensis* L.
	Prickly rose	*Rosa acicularis* Lindl.
	Veiny meadow-rue	*Thalictrum venulosum* Trel.
	Kinnikinnick	*Arctostaphylos uva-ursi* (L.) Spreng.
	Buckbrush	*Ceanothus cuneatus* (Hook.) Nutt.
	Stair-step moss	*Hylocomium splendens* Hedw.
S	Palmate-leaved coltsfoot	*Petasites palmatus* (Ait.) Cronq.
	Grass spp.	*Poaceae spp.*
	Wild strawberry	*Fragaria virginiana* Duchesne
	Bunchberry	*Cornus canadensis* L.
	Prickly rose	*Rosa acicularis* Lindl.
	Creamy peavine	*Lathyrus ochroleucus* Hook.
	Common Yarrow	*Achillea millefolium* L.
	Arrow-leaved coltsfoot	*Petasites sagittatus* Pursh.
	Kinnikinnick	*Arctostaphylos uva-ursi* (L.) Spreng.
W	Grass spp.	*Poaceae spp.*
	Wild Vetch	*Vicia americana* L.
	Northern bedstraw	*Galium boreale* L.
	Lowbush cranberry	*Viburnum edule* (Michx.) Raf.
	Bunchberry	*Cornus canadensis* L.
	Prickly rose	*Rosa acicularis* Lindl.
	Liliaceae spp.	*Lilium spp.*
	Twinflower	*Linnaea borealis* L.
	Creamy peavine	*Lathyrus ochroleucus* Hook.
	Arrow-leaved coltsfoot	*Petasites sagittatus* Pursh.

EMEND Site & Soil Assessment									
Site: 9C-Compt I: 940		Date: June 27, 16		GPS Coordinates: N: 56.81685 W: 118.37012					
Slope (%)	N: 2		E: 0		S: 4		W: 4		
Slope (˚)	N: 1		E: 0		S: 2		W: 2.5		
Slope position (lower, mid, upper):					Aspect (facing & deg.) SE 134˚				
Elevation (m) 696									
Dominant tree species: Aw			Number of dominant trees: 23				Record DBH below		
Centre	23.3								
N	23.8								
E	23.5								
S	22.7								
W	31.3								
Site average	24.92								
Secondary tree species:		Pb	Number of secondary trees: 3						
Ground cover (%) in a 1m x 1m square:		lichen	moss	leaf litter	needles	bare soil	CWD/Twigs	Total Live	Total Shrubs
	N	0	10	90	0	0	15	80	20
	E	0	0	90	0	0	0	70	10
	S	0	Trace	95	0	0	0	70	15
	W	0	Trace	100	0	0	0	40	5
	Site Average	0	5	93.75	0	0	3.75	65	12.5
Sampling location distance to nearest tree (cm):	N	140							
	E	130							
	S	140							
	W	150							
	Site Average	140							

Plants	Common name	Latin name with authority
N	Grass spp.	*Poaceae spp.*
	Wild strawberry	*Fragaria virginiana* Duchesne
	Bunchberry	*Cornus canadensis* L.
	Prickly rose	*Rosa acicularis* Lindl.
	Liliaceae spp.	*Lilium spp.*
	Creamy peavine	*Lathyrus ochroleucus* Hook.
	Veiny meadow-rue	*Thalictrum venulosum* Trel.
	Wild lily-of-the-valley	*Maianthemum canadensis* Desf.
E	Grass spp.	*Poaceae spp.*
	Wild strawberry	*Fragaria virginiana* Duchesne
	Northern bedstraw	*Galium boreale* L.
	Fireweed	*Chamerion angustifolium* (L.) Holub
	Bunchberry	*Cornus canadensis* L.
	Prickly rose	*Rosa acicularis* Lindl.
	Common Yarrow	*Achillea millefolium* L.
	Creamy peavine	*Lathyrus ochroleucus* Hook.
	Wild red raspberry	*Rubus idaeus L.*
	Veiny meadow-rue	*Thalictrum venulosum* Trel.
S	Grass spp.	*Poaceae spp.*
	Lowbush cranberry	*Viburnum edule* (Michx.) Raf.
	Bunchberry	*Cornus canadensis* L.
	Prickly rose	*Rosa acicularis* Lindl.
	Twinflower	*Linnaea borealis* L.
	Creamy peavine	*Lathyrus ochroleucus* Hook.
	Wintergreen spp.	*Pyrola spp.*
	Buckbrush	*Ceanothus cuneatus* (Hook.) Nutt.
W	Grass spp.	*Poaceae spp.*
	Northern bedstraw	*Galium boreale* L.
	Fireweed	*Chamerion angustifolium* (L.) Holub
	Bunchberry	*Cornus canadensis* L.
	Twinflower	*Linnaea borealis* L.
	Wintergreen spp.	*Pyrola spp.*
	Buckbrush	*Ceanothus cuneatus* (Hook.) Nutt.

EMEND Site & Soil Assessment									
Site: 10A-Compt D: 889		Date: June 26, 16		GPS Coordinates: N: 56.74874 W: 118.41718					
Slope (%)	N: 2		E: -1		S: 0		W: 3		
Slope (˚)	N: 1		E: 0.5		S: 0		W: 2		
Slope position (lower, mid, upper):					Aspect (facing & deg.) SW / 220˚'				
Elevation (m)	807								
Dominant tree species: Sw			Number of dominant trees: 10				Record DBH below		
Centre	25.3								
N	35.4								
E	20.5								
S	27								
W	19.2								
Site average	25.48								
Secondary tree species:		Pb	Number of secondary trees: 1						
Ground cover (%) in a 1m x 1m square:		lichen	moss	leaf litter	needles	bare soil	CWD/Twigs	Total Live	Total Shrubs
	N	Trace	40	40	40	0	0	80	25
	E	0	25	5	5	0	0	95	30
	S	10	90	5	5	0	0	100	5
	W	Trace	35	30	10	0	0	80	5
	Site Average	5	47.5	20	15	0	0	88.75	16.25
Sampling location distance to nearest tree (cm):	N	240							
	E	150							
	S	140							
	W	75							
	Site Average	151.25							

Plants	**Common name**	**Latin name with authority**
N	Bunchberry	*Cornus canadensis* L.
	Prickly rose	*Rosa acicularis* Lindl.
	Twinflower	*Linnaea borealis* L.
	Bishop's cap	*Mitella nuda* L.
	Stair-step moss	*Hylocomium splendens* Hedw.
E	Lowbush cranberry	*Viburnum edule* (Michx.) Raf.
	Bunchberry	*Cornus canadensis* L.
	Prickly rose	*Rosa acicularis* Lindl.
	Twinflower	*Linnaea borealis* L.
	Wintergreen spp.	*Pyrola spp.*
	Bishop's cap	*Mitella nuda* L.
	Knight's plume	*Ptilium crista-castrensis* (Hedw.) De Not.
	Stair-step moss	*Hylocomium splendens* Hedw.
S	Grass spp.	*Poaceae spp.*
	Bunchberry	*Cornus canadensis* L.
	Prickly rose	*Rosa acicularis* Lindl.
	Twinflower	*Linnaea borealis* L.
	Leather lichen spp.	*Unknown*
	Stair-step moss	*Hylocomium splendens* Hedw.
W	Grass spp.	*Poaceae spp.*
	Lowbush cranberry	*Viburnum edule* (Michx.) Raf.
	Bunchberry	*Cornus canadensis* L.
	Twinflower	*Linnaea borealis* L.
	Creamy peavine	*Lathyrus ochroleucus* Hook.
	Wild red raspberry	*Rubus idaeus L.*
	Bishop's cap	*Mitella nuda* L.
	Big red stem	*Pleurozium schreberi* Michx.
	Knight's plume	*Ptilium crista-castrensis* (Hedw.) De Not.
	Stair-step moss	*Hylocomium splendens* Hedw.

EMEND Site & Soil Assessment									
Site: 10B-Compt D: 889		Date: June 26, 16		GPS Coordinates: N" 56˚44'56.3" W: 118˚25'08.0"					
Slope (%)	N: 2		E: 1		S: 1		W: 0		
Slope (˚)	N: 1		E: 0.5		S: 0.5		W: 0		
Slope position (lower, mid, upper):					Aspect (facing & deg.) NW/N 338˚				
Elevation (m)	796								
Dominant tree species: Sw			Number of dominant trees: 21				Record DBH below		
Centre	27.3						27.3		
N	18.1						18.1		
E	16						16		
S	18						18		
W	14.2						14.2		
Site average	18.72								
Secondary tree species:		Pb	Number of secondary trees: 4 baby trees						
Ground cover (%) in a 1m x 1m square:		lichen	moss	leaf litter	needles	bare soil	CWD/Twigs	Total Live	Total Shrubs
	N	0	100	5	5	0	0	100	Trace
	E	Trace	100	5	5	0	Trace	100	0
	S	Trace	100	5	5	0	0	100	10
	W	Trace	100	Trace	5	0	0	100	0
	Site Average	0	100	5	5	0	0	100	3.33
Sampling location distance to nearest tree (cm):	N	120							
	E	150							
	S	121							
	W	120							
	Site Average	127.75							

Plants	Common name	Latin name with authority
N	Palmate-leaved coltsfoot	*Petasites palmatus* (Ait.) Cronq.
	Bunchberry	*Cornus canadensis* L.
	Prickly rose	*Rosa acicularis* Lindl.
	Twinflower	*Linnaea borealis* L.
	Bishop's cap	*Mitella nuda* L.
	Meadow horsetail	*Equisetum pratense* Ehrh.
	Knight's plume	*Ptilium crista-castrensis* (Hedw.) De Not.
	Stair-step moss	*Hylocomium splendens* Hedw.
E	Bunchberry	*Cornus canadensis* L.
	Liliaceae spp.	*Lilium spp.*
	Bishop's cap	*Mitella nuda* L.
	Meadow horsetail	*Equisetum pratense* Ehrh.
	Big red stem	*Pleurozium schreberi* Michx.
	Stair-step moss	*Hylocomium splendens* Hedw.
S	Bunchberry	*Cornus canadensis* L.
	Prickly rose	*Rosa acicularis* Lindl.
	Meadow horsetail	*Equisetum pratense* Ehrh.
	Big red stem	*Pleurozium schreberi* Michx.
	Knight's plume	*Ptilium crista-castrensis* (Hedw.) De Not.
	Stair-step moss	*Hylocomium splendens* Hedw.
W	Palmate-leaved coltsfoot	*Petasites palmatus* (Ait.) Cronq.
	Bunchberry	*Cornus canadensis* L.
	Bishop's cap	*Mitella nuda* L.
	Meadow horsetail	*Equisetum pratense* Ehrh.
	Electric eel	*Dicranum polysetum* Sw.
	Big red stem	*Pleurozium schreberi* Michx.
	Stair-step moss	*Hylocomium splendens* Hedw.

EMEND Site & Soil Assessment									
Site: 10C-Compt D: 889		Date: June 26, 16		GPS Coordinates: N: 56˚45'01.5" W: 118˚25'06.1"					
Slope (%)	N: 2		E: 2		S: 4		W: 2		
Slope (˚)	N: 1		E: 1		S: 2		W: 1		
Slope position (lower, mid, upper): lower					Aspect (facing & deg.) S/SW 230˚				
Elevation (m) 795									
Dominant tree species: Sw			Number of dominant trees: 4				Record DBH below		
Centre	43		* only 4 trees in plot				43		
E	27.9						27.9		
S	27.2						27.2		
W	57.6						57.6		
Site average	38.925								
Ground cover (%) in a 1m x 1m square:		lichen	moss	leaf litter	needles	bare soil	CWD/Twigs	Total Live	Total Shrubs
	N	0	25	5	5	0	25	50	5
	E	0	15	50	5	0	15	75	40
	S	Trace	0	50	5	0	5	60	15
	W	Trace	70	20	5	0	0	100	25
	Site Average	0	27.5	31.25	5	0	11.25	71.25	21.25
Sampling location distance to nearest tree (cm):	N	4							
	E	5							
	S	170							
	W	250							
	Site Average	107.25							

Plants	Common name	Latin name with authority
N	Grass spp.	*Poaceae spp.*
	Bunchberry	*Cornus canadensis* L.
	Prickly rose	*Rosa acicularis* Lindl.
	Wild red raspberry	*Rubus idaeus L.*
	Bishop's cap	*Mitella nuda* L.
	Meadow horsetail	*Equisetum pratense* Ehrh.
	Knight's plume	*Ptilium crista-castrensis* (Hedw.) De Not.
	Stair-step moss	*Hylocomium splendens* Hedw.
E	Grass spp.	*Poaceae spp.*
	Prickly rose	*Rosa acicularis* Lindl.
	Liliaceae spp.	*Lilium spp.*
	Wild red raspberry	*Rubus idaeus L.*
	Bishop's cap	*Mitella nuda* L.
	Meadow horsetail	*Equisetum pratense* Ehrh.
	Knight's plume	*Ptilium crista-castrensis* (Hedw.) De Not.
	Stair-step moss	*Hylocomium splendens* Hedw.
S	Lowbush cranberry	*Viburnum edule* (Michx.) Raf.
	Bunchberry	*Cornus canadensis* L.
	Prickly rose	*Rosa acicularis* Lindl.
	Twinflower	*Linnaea borealis* L.
	Wild red raspberry	*Rubus idaeus L.*
	Common horsetail	*Equisetum arvense* L.
	Bog Cranberry	*Vaccinium vitis-idaea* (L.) MacM.
	Sedge spp.	Unknown
W	Bunchberry	*Cornus canadensis* L.
	Prickly rose	*Rosa acicularis* Lindl.
	Twinflower	*Linnaea borealis* L.
	Wild red raspberry	*Rubus idaeus L.*
	Bishop's cap	*Mitella nuda* L.
	Common horsetail	*Equisetum arvense* L.
	Bog Cranberry	*Vaccinium vitis-idaea* (L.) MacM.
	Sedge spp.	Unknown
	Knight's plume	*Ptilium crista-castrensis* (Hedw.) De Not.
	Stair-step moss	*Hylocomium splendens* Hedw.

EMEND Site & Soil Assessment									
Site: 11A-Compt G: 918		Date: June 22, 16		GPS Coordinates: N: 56.79063 W: 118.36034					
Slope (%)	N: 4		E: 0		S: 0		W: 2		
Slope (˚)	N: 2		E: 0		S: 0		W: 1		
Slope position (lower, mid, upper):					Aspect (facing & deg.) W/NW 304˚				
Elevation (m) 730									
Dominant tree species: Sw			Number of dominant trees:				Record DBH below		
Centre	40.3								
N	23.3								
E	25.5								
S	26.1								
W	24.1								
Site average	27.86								
Ground cover (%) in a 1m x 1m square:		lichen	moss	leaf litter	needles	bare soil	CWD/Twigs	Total Live	Total Shrubs
	N	Trace	30	5	5	0	0	40	0
	E	Trace	0	5	5	0	0	40	Trace
	S	Trace	50	Trace	Trace	0	0	60	Trace
	W	Trace	25	5	5	0	0	60	0
	Site Average	#DIV/0!	26.25	5	5	0	0	50	0
Sampling location distance to nearest tree (cm):	N	85							
	E	120							
	S	300							
	W	90							
	Site Average	148.75							

Plants	Common name	Latin name with authority
N	Grass spp.	*Poaceae spp.*
	Twinflower	*Linnaea borealis* L.
	Lichen spp.	Unknown
	Stair-step moss	*Hylocomium splendens* Hedw.
E	Palmate-leaved coltsfoot	*Petasites palmatus* (Ait.) Cronq.
	Grass spp.	*Poaceae spp.*
	Lowbush cranberry	*Viburnum edule* (Michx.) Raf.
	Creamy peavine	*Lathyrus ochroleucus* Hook.
S	Grass spp.	*Poaceae spp.*
	Fireweed	*Chamerion angustifolium* (L.) Holub
	Bunchberry	*Cornus canadensis* L.
	Prickly rose	*Rosa acicularis* Lindl.
	Twinflower	*Linnaea borealis* L.
	Bishop's cap	*Mitella nuda* L.
	Stair-step moss	*Hylocomium splendens* Hedw.
W	Grass spp.	*Poaceae spp.*
	Fungi spp.	Unknown
	Stair-step moss	*Hylocomium splendens* Hedw.

EMEND Site & Soil Assessment

Site: 11B-Compt G: 918		Date: June 23, 16		GPS Coordinates: N: 56.79202 W: 118.36230					
Slope (%)	N: 69		E: 2		S: 9		W: 10		
Slope (˚)	N: 3.5		E: 1		S: 5.5		W: 6		
Slope position (lower, mid, upper): mid					Aspect (facing & deg.) N / 348˚				
Elevation (m) 740									
Dominant tree species: Sw			Number of dominant trees: 5				Record DBH below		
Centre	42.2								
N	24.4								
E	33.1								
S	30.3								
W	48.5								
Site average	35.7								
Ground cover (%) in a 1m x 1m square:		lichen	moss	leaf litter	needles	bare soil	CWD/Twigs	Total Live	Total Shrubs
	N	0	50	10	5	0	0	50	5
	E	0	5	Trace	5	0	0	100	15
	S	0	50	10	10	0	0	60	5
	W	0	80	10	5	0	0	100	5
	Site Average	0	46.25	10	6.25	0	0	77.5	7.5
Sampling location distance to nearest tree (cm):	N	130							
	E	165							
	S	90							
	W	80							
	Site Average	116.25							

Plants	Common name	Latin name with authority
N	Grass spp.	*Poaceae spp.*
	Fireweed	*Chamerion angustifolium* (L.) Holub
	Bunchberry	*Cornus canadensis* L.
	Prickly rose	*Rosa acicularis* Lindl.
	Balsam poplar	*Betula papyrifera* Marshall
	Moss spp.	Unknown
E	Palmate-leaved coltsfoot	*Petasites palmatus* (Ait.) Cronq.
	Grass spp.	*Poaceae spp.*
	Wild strawberry	*Fragaria virginiana* Duchesne
	Fireweed	*Chamerion angustifolium* (L.) Holub
	Bunchberry	*Cornus canadensis* L.
	Prickly rose	*Rosa acicularis* Lindl.
	Twinflower	*Linnaea borealis* L.
	Creamy peavine	*Lathyrus ochroleucus* Hook.
	Wild red raspberry	*Rubus idaeus L.*
	Asteraceae spp.	
	Bishop's cap	*Mitella nuda* L.
	Common horsetail	*Equisetum arvense* L.
	American milkvetch	*Astragalus americanus* (Hook.) M.E. Jones
	Knight's plume	*Ptilium crista-castrensis* (Hedw.) De Not.
	Stair-step moss	*Hylocomium splendens* Hedw.
S	Fireweed	*Chamerion angustifolium* (L.) Holub
	Bunchberry	*Cornus canadensis* L.
	Prickly rose	*Rosa acicularis* Lindl.
	Twinflower	*Linnaea borealis* L.
	Creamy peavine	*Lathyrus ochroleucus* Hook.
	Stair-step moss	*Hylocomium splendens* Hedw.
W	Highbush cranberry	*Virburnum opulus* L.
	Wild strawberry	*Fragaria virginiana* Duchesne
	Prickly rose	*Rosa acicularis* Lindl.
	Creamy peavine	*Lathyrus ochroleucus* Hook.
	Wild red raspberry	*Rubus idaeus L.*
	Bishop's cap	*Mitella nuda* L.
	Sweet-scented bedstraw	*Galium triflorum* Michx.
	Anemone spp.	*Unknown*
	Bunchberry	*Cornus canadensis* L.
	Knight's plume	*Ptilium crista-castrensis* (Hedw.) De Not.
	Stair-step moss	*Hylocomium splendens* Hedw.

EMEND Site & Soil Assessment									
Site: 11C-Compt G: 918		Date: June 23, 16	GPS Coordinates: N: 56˚47'33.6" W: 118˚21'55.2"						
Slope (%)	N: 7		E: 6		S: 3		W: 4		
Slope (˚)	N: 4		E: 3.5		S: 1.5		W: 2.5		
Slope position (lower, mid, upper): mid					Aspect (facing & deg.) NW / 326˚				
Elevation (m) 721									
Dominant tree species: Sw			Number of dominant trees: 6				Record DBH below		
Centre	41.9								
N	40.4								
E	25.3								
S	18.3								
W	40.3								
Site average	33.24								
Ground cover (%) in a 1m x 1m square:		lichen	moss	leaf litter	needles	bare soil	CWD/Twigs	Total Live	Total Shrubs
	N	Trace	25	50	5	0	0	75	Trace
	E	Trace	100	5	5	0	0	100	5
	S	Trace	85	5	5	0	0	100	0
	W	Trace	80	5	5	0	5	100	10
	Site Average	#DIV/0!	72.5	16.25	5	0	1.25	93.75	5
Sampling location distance to nearest tree (cm):	N	200							
	E	170							
	S	150							
	W	135							
	Site Average	163.75							

Plants	Common name	Latin name with authority
N	Bunchberry	*Cornus canadensis* L.
	Twinflower	*Linnaea borealis* L.
	Wild red raspberry	*Rubus idaeus L.*
	Bishop's cap	*Mitella nuda* L.
	Stair-step moss	*Hylocomium splendens* Hedw.
E	Fireweed	*Chamerion angustifolium* (L.) Holub
	Bunchberry	*Cornus canadensis* L.
	Prickly rose	*Rosa acicularis* Lindl.
	Twinflower	*Linnaea borealis* L.
	Wild red raspberry	*Rubus idaeus L.*
	Bishop's cap	*Mitella nuda* L.
	Knight's plume	*Ptilium crista-castrensis* (Hedw.) De Not.
	Stair-step moss	*Hylocomium splendens* Hedw.
S	Palmate-leaved coltsfoot	*Petasites palmatus* (Ait.) Cronq.
	Grass spp.	*Poaceae spp.*
	Fireweed	*Chamerion angustifolium* (L.) Holub
	Bunchberry	*Cornus canadensis* L.
	Bishop's cap	*Mitella nuda* L.
	Canada buffaloberry	*Shepherdia canadensis* (L.) Nutt
	Knight's plume	*Ptilium crista-castrensis* (Hedw.) De Not.
	Stair-step moss	*Hylocomium splendens* Hedw.
W	Grass spp.	*Poaceae spp.*
	Northern bedstraw	*Galium boreale* L.
	Fireweed	*Chamerion angustifolium* (L.) Holub
	Wild strawberry	*Fragaria virginiana* Duchesne
	Bunchberry	*Cornus canadensis* L.
	Prickly rose	*Rosa acicularis* Lindl.
	Liliaceae spp.	*Lilium spp.*
	Twinflower	*Linnaea borealis* L.
	Prickly rose	*Rosa acicularis* Lindl.
	Wild red raspberry	*Rubus idaeus L.*
	Knight's plume	*Ptilium crista-castrensis* (Hedw.) De Not.
	Stair-step moss	*Hylocomium splendens* Hedw.

EMEND Site & Soil Assessment									
Site: 12A-Compt G: 915		Date: June 25, 16		GPS Coordinates: N: 56.78694 W: 118.36583					
Slope (%)	N: 2		E: 2		S: 3		W: 4		
Slope (˚)	N: 1		E: 1		S: 2		W: 2		
Slope position (lower, mid, upper): upper/mid					Aspect (facing & deg.) S / 204˚				
Elevation (m) 727									
Dominant tree species: Sw			Number of dominant trees:				Record DBH below		
Centre	27								
N	24.2								
E	28.1								
S	16								
W	26.5								
Site average	24.36								
Secondary tree species:		Aw	Number of secondary trees: ~10 babies & 1 large						
Ground		lichen	moss	leaf litter	needles	bare soil	CWD/Twigs	Total Live	Total Shrubs
cover (%) ir	N	5	80	20	5	0	0	85	0
a 1m x 1m	E	Trace	60	25	5	0	0	70	0
square:	S	20	50	15	5	0	0	85	0
	W	5	90	15	5	0	0	100	5
	Site Average	10	70	18.75	5	0	0	85	1.25
Sampling	N	170							
location	E	140							
distance to	S	40							
nearest tree	W	110							
(cm):	Site Average	115							

Plants	Common name	Latin name with authority
N	Grass spp.	*Poaceae spp.*
	Bunchberry	*Cornus canadensis* L.
	Creamy peavine	*Lathyrus ochroleucus* Hook.
	Baby Aw	*Populus spp.*
	Lichen spp.	*Unknown*
	Knight's plume	*Ptilium crista-castrensis* (Hedw.) De Not.
	Stair-step moss	*Hylocomium splendens* Hedw.
E	Grass spp.	*Poaceae spp.*
	Bunchberry	*Cornus canadensis* L.
	Liliaceae spp.	*Lilium spp.*
	Big red stem	*Pleurozium schreberi* Michx.
	Stair-step moss	*Hylocomium splendens* Hedw.
S	Bunchberry	*Cornus canadensis* L.
	Creamy peavine	*Lathyrus ochroleucus* Hook.
	Bog Cranberry	*Vaccinium vitis-idaea* (L.) MacM.
	Big red stem	*Pleurozium schreberi* Michx.
	Stair-step moss	*Hylocomium splendens* Hedw.
W	Grass spp.	*Poaceae spp.*
	Bunchberry	*Cornus canadensis* L.
	Wild red raspberry	*Rubus idaeus L.*
	Baby Aw	*Populus spp.*
	Big red stem	*Pleurozium schreberi* Michx.
	Stair-step moss	*Hylocomium splendens* Hedw.

EMEND Site & Soil Assessment									
Site: 12B-Compt G: 918		Date: June 24, 16	GPS Coordinates: N: 56˚47'12.7" W: 118˚22'01.7"						
Slope (%)	N: 2		E: 2		S: 2		W: 2		
Slope (˚)	N: 1		E: 1		S: 1		W: 1		
Slope position (lower, mid, upper):					Aspect (facing & deg.) W/NW 292˚				
Elevation (m)	727								
Dominant tree species: Sw			Number of dominant trees: 7				Record DBH below		
Centre	37.1						37.1		
N	45.1						45.1		
E	19.8						19.8		
S	32.6						32.6		
W	30						30		
Site average	32.92								
Secondary tree species:		Aw	Number of secondary trees: 5						
Ground cover (%) in a 1m x 1m square:		lichen	moss	leaf litter	needles	bare soil	CWD/Twigs	Total Live	Total Shrubs
	N	0	90	0	0	0	0	100	5
	E	0	85	0	5	0	3	100	5
	S	Trace	95	5	5	0	0	100	0
	W	Trace	80	5	5	0	0	100	15
	Site Average	0	87.5	2.5	3.75	0	0.75	100	6.25
Sampling location distance to nearest tree (cm):	N	60	Notes: Bog cranberry present						
	E	160							
	S	130							
	W	170							
	Site Average	130							

Plants	Common name	Latin name with authority
N	Grass spp.	*Poaceae spp.*
	Wild strawberry	*Fragaria virginiana* Duchesne
	Bunchberry	*Cornus canadensis* L.
	Twinflower	*Linnaea borealis* L.
	Wild red raspberry	*Rubus idaeus L.*
	Bishop's cap	*Mitella nuda* L.
	Knight's plume	*Ptilium crista-castrensis* (Hedw.) De Not.
E	Big red stem	*Pleurozium schreberi* Michx.
	Grass spp.	*Poaceae spp.*
	Bunchberry	*Cornus canadensis* L.
	Prickly rose	*Rosa acicularis* Lindl.
	Twinflower	*Linnaea borealis* L.
	Creamy peavine	*Lathyrus ochroleucus* Hook.
	Wild red raspberry	*Rubus idaeus L.*
	Bishop's cap	*Mitella nuda* L.
	Wild lily-of-the-valley	*Maianthemum canadensis* Desf.
	Knight's plume	*Ptilium crista-castrensis* (Hedw.) De Not.
S	Creamy peavine	*Lathyrus ochroleucus* Hook.
	Bishop's cap	*Mitella nuda* L.
	Grass spp.	*Poaceae spp.*
	Bunchberry	*Cornus canadensis* L.
	Twinflower	*Linnaea borealis* L.
	Stair-step moss	*Hylocomium splendens* Hedw.
W	Wild red raspberry	*Rubus idaeus L.*
	Bishop's cap	*Mitella nuda* L.
	Wild lily-of-the-valley	*Maianthemum canadensis* Desf.
	Grass spp.	*Poaceae spp.*
	Bunchberry	*Cornus canadensis* L.
	Prickly rose	*Rosa acicularis* Lindl.
	Creamy peavine	*Lathyrus ochroleucus* Hook.
	Knight's plume	*Ptilium crista-castrensis* (Hedw.) De Not.
	Stair-step moss	*Hylocomium splendens* Hedw.

EMEND Site & Soil Assessment									
Site: 12C-Compt G: 918		Date: June 24, 16		GPS Coordinates: N: 56.78598 W: 118.36977					
Slope (%)	N: 9		E: 7		S: 2		W: 7		
Slope (˚)	N: 5		E: 4		S: 1		W: 4		
Slope position (lower, mid, upper):					Aspect (facing & deg.) W/NW 293˚				
Elevation (m)	723								
Dominant tree species: Sw			Number of dominant trees: 11				Record DBH below		
Centre	32						32		
N	20.1						20.1		
E	33.2						33.2		
S	33.1						33.1		
W	33.8						33.8		
Site average	30.44								
Ground cover (%) in a 1m x 1m square:		lichen	moss	leaf litter	needles	bare soil	CWD/Twigs	Total Live	Total Shrubs
	N	Trace	95	Trace	5	0	8	100	0
	E	Trace	100	Trace	5	0	5	100	Trace
	S	Trace	100	5	5	0	3	100	0
	W	Trace	95	5	5	0	0	100	0
	Site Average	0	97.5	5	5	0	4	100	0
Sampling location distance to nearest tree (cm):	N	190							
	E	120							
	S	150							
	W	80							
	Site Average	135							

Plants	Common name	Latin name with authority
N	Wild strawberry	*Fragaria virginiana* Duchesne
	Northern bedstraw	*Galium boreale* L.
	Liliaceae spp.	*Lilium spp.*
	Twinflower	*Linnaea borealis* L.
	Creamy peavine	*Lathyrus ochroleucus* Hook.
	Baby Pb	*Betula spp.*
	Stair-step moss	*Hylocomium splendens* Hedw.
E	Grass spp.	*Poaceae spp.*
	Bunchberry	*Cornus canadensis* L.
	Wild red raspberry	*Rubus idaeus L.*
	Stair-step moss	*Hylocomium splendens* Hedw.
S	Wild strawberry	*Fragaria virginiana* Duchesne
	Bunchberry	*Cornus canadensis* L.
	Twinflower	*Linnaea borealis* L.
	Creamy peavine	*Lathyrus ochroleucus* Hook.
	Bishop's cap	*Mitella nuda* L.
	Knight's plume	*Ptilium crista-castrensis* (Hedw.) De Not.
	Stair-step moss	*Hylocomium splendens* Hedw.
W	Grass spp.	*Poaceae spp.*
	Bunchberry	*Cornus canadensis* L.
	Twinflower	*Linnaea borealis* L.
	Creamy peavine	*Lathyrus ochroleucus* Hook.
	Bishop's cap	*Mitella nuda* L.
	Knight's plume	*Ptilium crista-castrensis* (Hedw.) De Not.
	Stair-step moss	*Hylocomium splendens* Hedw.

Appendix 2. Athabasca oil sands site and soil descriptions

Site and Soil Assessment Form

Slope: N: -13% , 7.5° S: -8% , 45° E: -6% , 3° W: -1% , 0.5°	**Aspect (deg):** North (w) ,334°	**Observers: Cassandra, Brittany** **Slope position: Middle** — **Reclaimed** **Other Notes** : Syncrude 30D - on the L while walking towards Bill's Lake Next to research plot	
Date: August 21,2015	**Site 1**	**GPS Coordinates: N 56.99871 W -111.61543**	
Tree species: Sw, Aw	**Number of trees (20 m by 20 m)** 20	**Average Sw DBH** 6.44	

dbh (cm): Aw	2.8	1	1.5	5.7					
dbh (cm): Sw	5.1	5.1	3	4.4	9.9	8	10.4	4.5	4.3
	4.9	6.2	7.5	10.3	6.5	5.4	4.8		

	N:	E:	S:	W:	Dominant understory
Understory	Rubus idaeus, Fireweed, Dandelion, Grass, Creamy peavine, Yellow sweet clover, Alfalafa	Rubus idaeus, Dandelion, Grass, Fireweed, Purple peavine , Bedstraw	Fireweed, Rubus idaeus, Canada thistle	Rubus idaeus, Fireweed, Canada thistle, Purple peavine, Grass	Grass (Poaceae spp), Fireweed (Epilobeum angustifolium), Raspberry (Rubus idaeus)

Ground cover (1 m by 1 m)	**Ground cover (%)**								**Sampling distance to nearest tree**
	lichen	*moss*	*leaf litter*	*needles*	*bare soil*	*CWD (twigs)*	*live*	*shrubs*	
N	0	0	100	0	0	0	100	10	**N** 145 cm (Aw)
E	0	0	100	0	0	0	100	6	**E** 155 cm (Sw)
S	0	0	8	0	0	100	47	42	**S** 100 cm (Aw)
W	0	0	100	0	0	2	95	12	**W** 150 cm (Sw)
Site Average	0	0	77	0	0	25.5	85.5	17.5	

Site and Soil Assessment Form

Slope (%): N: -2% , 1° S: -3% , 2° E: -3% , 2° W: -4% , 2°	**Aspect (deg):** SouthEast facing, 150°	**Observers: Cassandra, Brittany** **Slope position: Middle** — **Reclaimed** **Other Notes** Syncrude Could not install rebar	
Date: August 20,2015	**Site 2**	**GPS Coordinates: N 57.01005 W -111.72236**	
Tree species: Aw, Sw, Salix spp.	**Number of trees (20 m x 20 m)** 42	**Average Aw DBH** : 2.01	

dbh (cm): Aw	2.5	2.9	1.8	0.5	1.3	3.2	1.2	1.3 (10+)	1.3 (10+)	1.9 (10+)	1.7
	1.3	1.9	0.8	0.9	1.7	4.4	1.3	1.7	2.8	.5 (10+)	2.7
	0.7	1.4 (10+)	3	3.5	1.7	0.7	2.8	2.5	2.7	2.6	
dbh (cm): Sw	1	2.7	3 (10+)	3.5 (10+)	1.5 (10+)	2.8 (10+)	2.7 (10+)	1.3 (10+)	3.0 (10+)	2.5 (10+)	

	N:	S:	E:	W:	Dominant understory
Understory	Wild strawberry, grass, dandelion , Aster ciliolatus, vetch, Achillea millefolium, Equisetum pratense, Arctostaphylos uva-ursi, Rubus idaeus	Fragaria virginiana. Arctostaphylos uva-ursi, Equisetum pratense, Vetch, Achillea millefolium, Dandelion, Grass, Rubus idaeus, Aster ciliolatus, Narrow-leaved hawkweed, Unknown lichen (same as E)	Fragaria virginiana, Equisetum pratense, Rubus idaeus, Grass , Dandelion, Arctostaphylos uva-ursi, Vetch, Achillea millefolium, Rosa acicularis. Aster ciliolatus, Unknown lichen (collected)	Fragaria virginiana, unknown vetch spp. (same as N), grass, Arctostaphylos uva-ursi, Rubus idaeus, Achillea millefolium, Dandelion	Wild strawberry (Fragaria virginiana), Bearberry (Arctostaphylos uva-ursi), Vetch (Vicia spp.)

Ground cover (1 m by 1 m)	**Ground cover (%)**								**Sampling distance to nearest tree**
	lichen	*moss*	*leaf litter*	*needles*	*bare soil*	*CWD (twigs)*	*live*	*shrubs*	
N	0	30	44	0	0.5	2	92	0	**N** 76 cm
E	2	53	24	0	0	2	120	6	**E** 71 cm
S	0.5	14	11	0	0	0	114	0	**S** 110 cm
W	0	5	21	0	0	0.5	97	8	**W** 77 cm
Site Average	0.625	25.5	25	0	0.125	1.125	105.75	3.5	

Site and Soil Assessment Form

Observers: Cassandra, Brittany

Slope (%): N: -6% , 5.5°; S: -6% , 3.5°; E: -2% , 1°; W: -4% , 2.5°

Aspect (deg): SouthEast, 174°

Slope position: Flat | **Reclaimed**

Other Notes : Syncrude 30D - Bill's Lake
lots of Salix spp. Or pincherry?

Date: August 21,2015 | **Site 3** | **GPS Coordinates: N 57.00123 W -111.60873**

Tree species: Aw, Pb | **Number of trees (10 m by 10 m)**: 43 | **Average Aw DBH** : 5.89

dbh (cm): Aw									
4.6	7	6.5	2.3	3.3	2.2	2 (10+)	20.5	2.3	10.5
4	14.3	2.2	0.2	2.2	6.2	1.3	16.7	9.8	4.5
2.8	3.9	3.1	3.9	17.4	8.5	6	3.5	3.7	2
3.3	7	8.7	3.7	9.4	1.3	1.5			

dbh (cm): Pb					
17	16.1	19.5	16.5	15	19.5

Understory	N:	S:	E:	W:	Dominant understory
	Aster cilliolatus, Grass, Dandelion, Canada thistle, Wintergreen spp, Rubus pubescens, Blunt leaved sandwort	Dandelion, Fireweed, Grass, Canada thistle, White spruce, Rubus pubescens (same as N), Hempnettle (collected)	Fireweed, Dandelion, Grass, Rubus idaeus	Dandelion, Grass, Rubus pubescens, Wintergreen spp. (same as N), White spruce, Fireweed, Yellow sweet clover	Dandelion (Taraxacum officianale), Fireweed, Raspberry (Rubus ideaus)

Ground cover (1 m by 1 m) — **Ground cover (%)**

	lichen	*moss*	*leaf litter*	*needles*	*bare soil*	*CWD*	*live*	*shrubs*	Sampling distance to nearest tree (Aw)
N	0	0	96	0	3	1	39	0	N 159 cm
E	0	0	100	0	0	8	10	7	E 47 cm
S	0	0	100	0	0	2	60	0	S 61 cm
W	0	0	100	0	0	0	49	0	W 27 cm
Site Average	0	0	99	0	0.75	2.75	39.5	1.75	

Site and Soil Assessment Form

Observers: Cassandra, Brittany

Slope (%): NW: -10% ,; SE: -15% , 8.5°; NE: -12% , 7°; SW: -13% , 7.5°

Aspect (deg): NorthWest facing, 320°

Slope position: Middle | Reclaimed

Other Notes Sampled July 11, 2015, Measured DBH Aug 21

Date: August 21,2015 | **Site 4** | **GPS Coordinates: N 56.99556 W -111.61914**

Tree species: Aw, Pb | **Number of trees (20 m by 20 m)**: 215 Aw, 21 Sw = 236 | **Average DBH** 4.04

dbh (cm): Aw									
2.2	1.9	3.7	5.5	3.8	2.6	0.9	3.2	1.3	3.3
3.7	3.9	2.5	1.8	2.8	1.3	3.6	3.2	4.5	1.7
8.7	3.7	8.6	5.4	5.7	9.1	2.5	8.4	1.3	7
9.5	2.5	4.3	9.1	2	2.4	3.3	2.5		

Understory	SW:	SE:	NE:	NW:	Dominant understory
	Rubus idaeus, Dandelion, Canada thistle, Trifloium hybridum	Fragaria virginiana, Canada thistle, Achillea millefolium, Dandelion, Alsike clover, Yellow sweet clover, Grass	Fireweed, Dandelion, Alsike clover, Achillea millefolium, Rubus idaeus, Purple peavine	Dandelion, alsike clover, Achillea millefolium, Canada thistle, Rubus idaeus, Yellow sweet clover, Grass	Dandelion (Taraxacum officinale) Achillea millefolium, Alsike clover (Trifolium hybridum)

Ground cover (1 m by 1 m) — **Ground cover (%)**

	lichen	*moss*	*leaf litter*	*needles*	*bare soil*	*CWD*	*live*	*shrubs*	Sampling distance to nearest tree
SW	0	0	100	0	0	4	31	1	SW 39 cm
NW	0	0	100	0.5	0	2	50	0	NW 52 cm
SE	0	0	100	0	0	10	13	1	SE 69 cm
NE	0	0	100	0	0	2	17	0	NE 59 cm
Site average	0	0	100	0.125	0	4.5	27.75	0.5	

Site and Soil Assessment Form

Observers:	Cassandra, Brittany
Slope	N: -1% , 0.5° E: -4% , 2.5° S: +2% , 1° W: -0% , 0°
Aspect (deg):	NE 60˚
Slope position:	Flat, Natural
Other Notes	: Syncrude Sw Stand *Thick cover of dust on everything. B/w 2 roads Hill of sand across road that runs on the NW side of the site
Date:	August 23,2015
Site	Site 5
Tree species:	Sw, Lt, Pb, Aw
Number of trees (20 m by 20 m):	46
GPS Coordinates:	N 56.94395 W -111.73924
Average DBH	9.07

dbh (cm): Sw	3.7	9.3	23.3	6.1	11	14	1.5	23.3
	1.7	24.7	2.4	34.2	10.1	1.7	24.7	1.7 (10+)
	21.7	4.9	3.9	3.9	4.5	2.4 (10+)	8.7	
dbh (cm): Pb	16.5	1.6	13.2	2.5	2.1			
dbh (cm): Aw	1.6	6.1	9	5.4	11.6	12.8		
dbh (cm): Lt	4.9	1.6	1.5	3.3	1.5	9.6		
	5.1	11.3	14.3	4.3	2.8	3		

	N	S	E	W	Dominant understory
Understory	Palmate leaved coltsfoot, Wild strawberry, Buffaloberry, Bunchberry, Rosa acicularis, Northern Bedstraw, Twinflower, Moss, Wild lily of the valley, Trintalis borealis, Bog cranberry, Shrubby cinquefoil, Grass, lily spp., Aster cilliolatus	Wild strawberry, Labrador tea, Moss, Palmate leaved coltsfoot , Bunchberry, Rosa acicularis, Grass, Achillea millefolium, Twinflower, Buffaloberry	Rosa acicularis, Dwarf birch, Wild strawberry, Moss, Palmate leaved coltsfoot, Labrador tea, Twinflower, Grass Bog cranberry, Willow spp., Lily spp., Northern starflower	Rosa acicularis, Labrador tea , Wild straw, Bog cranberry, Palmate leaved coltsfoot, Buffaloberry, Grass, Moss, Bunchberry, Twinflower, Bishop's cap, Meadow horsetail, Aster cilliolatus	Palmate leaved coltsfoot (Petasites palmatus), Rosa acicularis, Bunchberry (Cornus canadensis)

Ground cover (1 m by 1 m)	Ground cover (%)								Sampling distance to nearest tree (Sw)
	lichen	*moss*	*leaf litter*	*needles*	*bare soil*	*CWD*	*live*	*shrubs*	
N	0	18	46	28	0	24	39	0	N 220 cm
E	0	27	47	25	0	6	10	7	E 95 cm
S	0	44	21	3	0	30	60	0	S 200 cm
W	0	1	30	1	0	0	49	0	W 114 cm
Site Average	0	22.5	36	14.25	0	15	39.5	1.75	

Site and Soil Assessment Form

Observers:	Cassandra & Brittany
Slope:	N: -3.2%, 2˚ E: -5%, 3˚ W: 0% 0˚
Aspect (deg):	NorthWest, 279°
Slope position:	Flat, Natural
Other Notes	: Syncrude SWSS
Date:	August 24,2015
Site	Site 6
GPS Coordinates:	N 56.96378 W -111.72173
Tree species:	Aw, Sw
Number of trees (20 m by 20 m)	40
Average Aw DBH	9.73

dbh (cm): Aw	20.9	23.8	21.7	1.5	1.5	31.4	1.4	23.6	4
	1.5	2.5	4	0.9	29.4	24.3	2.3	1.8	1.5
	29.8	2.2	0.9	24	3.3	1.5	2.3	1.6	1.3
	16.9	0.5	1.6	25.7	1.3	2.3	26.6	3	1
dbh (cm): Sw	7	14.2	12.8	11.5					

	N	S	E	W	Dominant understory:
	Bunchberry, Rosa acicularis, Twinflower, Lab. Tea , Northern Bedstraw, Wild lily of the valley, Lycopodium annotinum, Northern Star-flower, Wild strawberry, Small bog cran., moss (collected), Labrador lousewort	Stair-step moss, Twin flower, Northern bedstraw, Bunchberry, Bog cranberry, Wild lily of the valley , moss (collected), Rosa acicularis, Labrador lousewort, Fireweed, common yarrow, fabaceae spp.. Red	Bunchberry, buffaloberry, Labrador tea, wild strawberry, Twinflower, Wild lily of the valley, Bog cranberry, Fireweed, Blueberry, High bush cranberry, Moss Grass, Northern Starflower, Northern	Palmate-leaved coltsfoot, Red-oiser dogwood, Bunchberry, Wild strawberry, Buffaloberry, Rosa acicularis, Twinflower, Bishop's cap, Wild sarsparilla, Moss, Wild lily of the valley, Lab. Lousewort, Wild red raspberry	Bunchberry (Cornus canadensis), Twinflower (Linnaea borealis), Rosa acicularis

Ground cover (1 m by 1 m)	Ground cover (%)								Sampling distance to nearest tree (Aw)
	lichen	*moss*	*leaf litter*	*needles*	*bare soil*	*CWD*	*live*	*shrubs*	
N	0	4	98	0	0	7	66	23	N 85 cm
E	0	2	98	0	0	12	60	17	E 143 cm
S	0	30	44	0	0	21	60	2	S 150 cm
W	0	11	94	0	0	9	50	13	W 70 cm
Site Average	0	11.75	83.5	0	0	12.25	59	13.75	

Site and Soil Assessment Form

Observers: Cassandra, Brittany

Slope %	N: -1% , 0.5° E: -2% , 1°	**Slope position:** Flat	Natural
	S: -1% , 0.5° W: -1% , 0.5°	**Other Notes** : Syncrude SWSS	
Date: August 24,2015	**Site 7**	**GPS Coordinates: N 56.95859 W -111.72289**	

Tree species: Aw, Sw | **Number of trees (20 m by 20 m)** 41 | **Average Aw DBH** 9.72

dbh (cm): Aw									
1.5	20.6	22.4	21.7	20	0.7	3.8	2.3	1.2	2.3
21.4	21	1.8	0.6	0.4	2.3	1	28.6	21.1	2.4
3.5	3.6	2.7	20.8	8.8	20.7	0.5	3.7	2.3	4.7
26.5	1.2	1.5	19.5	22.9	25.6	2.3	1.4		

dbh (cm): Pb 3.5, 3 | **dbh (cm): Sw** 1.1

N: Wild strawberry, bunchberry, prickly rose, palmate leaved coltsfoot, low bush cranberry, bog cranberry, wild red raspberry northern bedstraw, twinflower, wild lily of the valley, buffaloberry, labradoe lousewort, grass, lindley's aster.	**S:** Bunchberry, Fireweed, Prickly rose, Palmate leaved coltsfoot, Bog cranberry, Northern bedstraw, Twinflower, Wild lily of the valley, grass, Lindley's aster, Bishop's cap, Labrador tea	**E:** Bunchberry, Fireweed, Prickly rose, Palmate leaved coltsfoot, Bog cranberry, Twinflower, Grass, Lindley's aster, Common blueberry, Northern starflower	**W:** Wild strawberry, Bunchberry, Prickly rose, Bog cranberry, Northern bedstraw, Twinflower, Wild lily of the valley, Grass, Lindley's aster, Common blueberry, Moss spp, Northern starflower, Lichen spp.	**Dominant understory:** Bunchberry (Cornus canadensis), Palmate leaved coltsfoot (Petasites palmatus), Twinflower (Linnaea borealis)

Ground cover (1 m by 1 m) — **Ground cover (%)**

	lichen	*moss*	*leaf litter*	*needles*	*bare soil*	*CWD*	*live*	*shrubs*	Sampling distance to nearest tree (Aw)	
N	0	0	93	0	0	7	74	12	N	86 cm
E	0	0	100	0	0	10	68	10	E	136 cm
S	0	0	100	0	0	0	84	8	S	90 cm
W	0.5	10	92	0	0	10	77	12	W	129 cm
Site Average	0.125	2.5	96.25	0	0	6.75	75.75	10.5		

Site and Soil Assessment Form

Observers: Cassandra, Brittany

Slope (%): N: -4% , 1.5°	**Aspect (deg):** NW 344°	**Slope position:** Lower-middle	**Reclaimed**
E: -8% , 4° S: -8% , 4°		**Other Notes** : Syncrude W1 Site	
W: -4% ,		(Shared with Emily)	
Date: August 24,2015	**Site 8**	**GPS Coordinates: N: 57.01005 W: -111.72236**	

Tree species: Aw, Sw | **Number of trees (20 m x 20 m)** 35 | **Average Aw DBH** 1.29

dbh (cm): Aw	0.8	2.3	1 (10+)	1.4 (10+)	0.7 (10+)	1.5	2.4	1.6	1	0.8	1.3
	0.5	1.5	0.8 (10+)	1 (10+)	1.2	1.5	1.8	1.8	0.7	1.5	
dbh (cm): Sw	2.3	1.3	1.3	1.4	2.5 (10+)	1	1 (10+)	1.3	1.7	1.3	1.2
	1.1	1	1.4								

Understory	**N:** Wild vetch (Vicia americana), Wild strawberry, Fireweed, Alsike clover, Dandelion, White sweet clover (Melilotus albus), Grass, Meadow horsetail, Moss, Achillea millefolium, Dwarf raspberry?, Aster	**S:** Wild red straw., Dwarf rasp? (same as N), Grass, Meliolatus albus, Vicia americana, Fireweed, Dandelion, Red-oiser dogwood, Achillea millefolium , Alsike clover, Moss (collected),	**E:** Grass, Wild red rasp., Dandelion	**W:** Achillea millefolium, Alsike clover, Dandelion, White sweet clover, Meadow horsetail Grass , Strawberry, Wild vetch, Achillea millefolium , Moss	Dominant understory: Meadow horsetail, Grass, Wild vetch

Ground cover (1 m by 1 m) — **Ground cover (%)**

	lichen	*moss*	*leaf litter*	*needles*	*bare soil*	*CWD*	*live*	*shrubs*	**Sampling distance to nearest tree (Aw)**	
N	0	3	37	0	0.5	0	67	0	N	70 cm
E	0	0	100	0	0	0	100	0	E	170 cm
S	0	6	22	0	5	1	101	4	S	60 cm
W	0	3	22	0	0	1	100	0	W	100 cm
Site Average	0	3	45.25	0	1.375	0.5	92	1		

Site and Soil Assessment Form

Site and Soil Assessment Form		**Observers: Cassandra, Brittany**		
Slope (%): N: -7% , 4.5°	**Aspect (deg):** NW 274°	**Slope position: Lower - Middle**	**Natural**	
E: -7% , 4.5° S: -0% , 0°		**Other Notes** : N Hwy 63 Sw Stand	* Rebar placed	
W: -5% , 3°				
Date: August 22,2015	**Site 9**	**GPS Coordinates: N 57.26284 W -111.63018**		
Tree species: Sw, Aw, Bw	**Number of trees (20m x 20m)** 28		**Average Sw DBH** 17.28	

dbh (cm): Sw	18.4	8.1	47.6	23.1	17.7	36.2	36	37.2	16.3	
dbh (cm): Pb	1.2	0.9	0.7	1.5	2.6	0.7	1.1	25.8	35.9	
dbh (cm): Aw	0.8	0.8	1.2 (10+)	2.1	1.2	1.5	0.6	0.4	1.5	0.8

	N:	S:	E:	W:	Dominant understory
Understory	Cornus canadensis, Rosa acicularis, Pleurozium schreberi, Wild red currant (Ribes triste), Palmate leaved coltsfoot, Equisetum pratense, Gallium trifitum, Linnaea borealis, Mitella nuda, Maianthemum canadense	Rubus ideaeus, Equisetum pratense, Mitella nuda, Cornus canadensis, Rosa acicularis, Moss (collected)	Wild sarsaparilla, Bunchberry, Labrador tea, Rosa acicularis, Mitella nuda, Equisetum pratense (6), Rubus idaeus , Low bush cranberry, Moss (collected)	Petasites palmatus, Mitella nuda, Cornus canadensis, Equisetum pratense, Rubus idaeus, Gallium trifitum, Wild sarsaparilla, Moss (collected)	Mitella nuda, Prickly rose, Equisetum pratense

Ground cover (1 m by 1 m)	**Ground cover (%)**								Sampling distance to nearest tree
	lichen	***moss***	***leaf litter***	***needles***	***bare soil***	***CWD***	***live***	***shrubs***	
N	0	100	50	40	0	9	178	4	N 227 cm Pb
E	4	48	58	30	0	20	123	6	E 211 cm Sw
S	0	43	20	40	0	20	105	18	S 112 cm Sw
W	0	25	17	40	0	10	112	4	W 105 cm Sw
Site Average	1	54	36.25	37.5	0	14.75	129.5	8	

Site and Soil Assessment Form

Site and Soil Assessment Form		**Observers: Cassandra, Brittany**		
Slope (%): N: -14% , 8° E: -25%, 14° S: -13%, 7.5° W: -	Aspect (deg): SW 226°	Slope position: Middle(S,W) and upper (N, E)		Reclaimed
Date: Aug 22,2015	**Site 10**	**GPS Coordinates:**	**N: 57.25674, W: -111.62381**	
Tree species: Aw	**Number of trees (20 m x 20 m)**	26	Avg Aw DBH 10.98	

	1.5	22.1	19.4	18.7	0.7	0.6	0.9	0.6	0.7
dbh (cm)	17.2	17.1	0.6	17.4	17.7	16.2	1.1	19.1	19.3
	16.5	14.6	16.4	24.2	1.8	1	1.7	18.2	

Understory	**N**: Maianthemum canadense, bunchberry, twinflower, saskatoon, wild sasparilla, fireweed, fragaria virginiana,grass, rosa acicularis, gallium boeral	**E** twinflower, bunchberry, rosa acicularis, wild sasparilla, saskatoon, symphoricarops occidentalis, bearberry, bog cranberry, strawberry, gallium boreal, moss	**S**: buffaloberry, bunchberry, twinflower, rosa acicularis, palmate-leaved coltsfoot, labrador tea, mitella nuda, foreweed, bog cranberry, moss, northern bedstraw, grass, wild red currant, blueberry, wild lily of the	**W**: Rosa acicularis, Buffaloberry, Grass, Bunchberry, Wild lily of the valley, twinflower, bog cranberry, northern bedstraw, showy aster	**Dominant understory** Bunchberry (Cornus canadensis), Twinflower (Linnaea borealis), Rosa acicularis

Ground cover (1 m by 1 m)	**Ground cover (%)**								Sampling distance to nearest tree
	lichen	***moss***	***leaf litter***	***needles***	***bare soil***	***CWD (twigs)***	***live***	***shrubs***	
N	0	3	98	0	0	6	63	8	N: 300 cm Aw
E	0	0.5	80	0	0	15	88	5	E: 280 cm Aw
S	0	5	98	0	0	9	80	20	S: 127 cm Aw
W	0	1.5	93	1	0	11	46	16	W: 110 cm Aw
Site Average	0	2.5	92.25	0.25	0	10.25	69.25	12.25	

Site and Soil Assessment Form		**Observers: Cassandra, Brittany**		
Slope (%): N: -15% , 8.5° E: -17%, 9.5° S: -	Aspect (deg): NE, 61 deg	Slope position: Middle	**Reclaimed**	
Date:Aug 24, 2015	**Site 11**	**GPS:N: 57.08326, W: -111.61208**		
Tree species: Aw		**Number of trees (20 m by 20 m): 87**	Average Aw DBH	5.98
dbh (cm)	Aw: 2.5, Aw: 2, Aw: 9.4, Aw: 10.7, Aw: 2.2, Aw: 11.9, Aw: 7.8, Aw: 10.7, Aw: 6.8, Aw: 14.1, Aw: 9.7, Aw: 4.4, Aw: 1.3, Aw: 0.9, Aw: 2.8, Aw: 1.5, Aw: 1, Aw: 0.8, Aw: 10, Aw: 3.5, Aw: 5.8, Aw: 6.9, Aw: 9.3, Aw: 4.3			

Main shrubs and understory plants	**N:** wild red raspberry, grass, dandelion, fabaceae spp., aster ciliolatus, alsike clover, lotus corniculatu	**E:** grass, dandelion, wild red raspberry, wild strawberr y	**S:** Raspberry, aster ciliolatus, grass, dandelion, fabaceae spp. lotus corniculatus	**W**: Rasp. Yellow flowerings, grass, fabaceae spp., lotus corniculatus	NOTE: Red osier dogwood throughout site	**Sampling distance to nearest tree (Aw)** N: 50 cm E: 70 cm S: 130 cm W: 100 cm	**Dominant understory:** Grass (Poaceae spp.), Dandelion (Taraxacum officinale), Wild red raspberry (Rubus ideas),

Ground cover (1 m by 1 m) **Ground cover (%)**

	lichen	*moss*	*leaf litter*	*needles*	*bare soil*	*CWD (twigs)*	*live*	*shrubs*
N	0	0	100	0	0	0	33	5
E	0	1	100	0	0	0	44	1
S	0	0	100	0	0	0	40	26
W	0	0	100	0	0	0	37	8
Site Average	0	0.25	100	0	0	0	38.5	10

Site and Soil Assessment Form		**Observers: Cassandra, Brittany**	
Slope (%): NE: 1% , -1° SE: 0 NW: 1%, 1° SW: 1%, 1°	Aspect (deg)	**Slope position:** Flat	**Reclaimed**
Date:July 18,2015	**Site 12**	**GPS Coordinates:** N: 56.99108, W: -111.56409	
Tree species: Aw, Sw, Aw, Sw	**Number of trees (20m x 20m):** 15		**Average Aw DBH:** 12.22
dbh (cm)	Aw: 12.8, Aw: 10.3, Aw: 14.2, Aw: 8.5, Aw: 10.1, Aw: 5.2, Aw: 14.8, Aw: 13.7, Aw: 14.2, Aw: 11.1, Aw: 11.9, Aw: 10.1, Aw: 14.2, Aw: 16.4, Aw: 15.8		

Understory	**NE:** meadow horsetail, wild smooth strawberry, marsh redd grass, dandelion,	**SE:** wild red raspberry, wild smooth strawberry, dandelion, meadow horsetail	**SW:** dandelion	**NW:** common pink wintergreen	**Dominant understory:** Common pink wintergreen, Wild strawberry, Marsh reed	Sampling distance to nearest tree (Aw):

Ground cover (1 m by 1 m) **Ground cover (%)**

	lichen	*moss*	*leaf litter*	*needles*	*bare soil*	*CWD (twigs)*	*live*	*shrubs*
NE	0	0.2	100	25	0	12	10	0
SE	0	0.4	75	40	0	10	6	1
SW	0	0.2	70	40	0	9	18	0
NW	0	3	50	50	0	8	3	0
Site Average	0	0.95	73.75	38.75	0	9.75	9.25	0.25

Site and Soil Assessment Form

Site and Soil Assessment Form		Observers: Cassandra, Brittany	
Slope (%): N: -3% , 2° E: -2%, 1° S: -2%, 1˚ W:	Aspect (deg): S,181°	**Slope position:** Flat	Reclaimed
Date:Aug 19 2015	**Site 13**	**GPS Coordinates N: 56.99253, W: -111.56313**	
Tree species: Sw, Dogwood, Aw	**Number of trees (20m x 20m):** 27		

DBH (cm) Sw	Sw: 14.5, Sw: 21, Sw: 10.9, Sw: 14.7, SwL 16.5, Sw: 15.2, Sw: 15.9, Sw: 13.8, Sw: 19.1, Sw: 14.2, Sw: 5.5, Sw: 18.5, Sw: 15.8, Sw: 20.2, Sw: 14.1, Sw: 20.5
DBH (cm) Aw	Aw: 5.5, Aw: 7.5, Aw: 5.6, Aw: 6.5, aw: 7.0, Aw: 6.0, Aw: 9.3, (??): 0.9, Aw: 12.9, Aw: 7.3

Understory	**N:** wild strawberry, 3 mosses, 2 lichen, aster ciliolatus	**E:** grass, rosa acicularis	**S:** lesser wintergree, grass, moss, unkonwn shrub	**W:** dandelion, lesser wintergreen, moss	**Dominant understory:** Lindley's Aster (Aster ciliolatis), Moss spp., Lesser wintergreen (Pyrola minor)	**Sampling distance to nearest tree (Sw)** N: 100 cm E: 52 cm S: 81 cm W: 92 cm

Ground cover (1 m by 1 m) — **Ground cover (%)**

	lichen	*moss*	*leaf litter*	*needles*	*bare soil*	*CWD (twigs)*	*live*	*shrubs*
NE	2	4	0	100	0	4	7	0
SE	0	0	12	100	0	6	2	0.4
SW	0	4	22	100	0	20	11	4
NW	0	2	50	100	0	40	0	0
Site Average	0.5	2.5	21	100	0	17.5	5	1.1

Site and Soil Assessment Form

Site and Soil Assessment Form		**Observers: Cassandra, Brittany**	
Slope (%): NE: -15% , 8.5° E: -15%, 8.5° S: -16%, 9° W: -20%, 12°		**Slope position:** Middle	**Reclaimed**
20-Aug-15	**Site 14**	**GPS Coordinates** N: 56.99326, W: -111.57085	
Tree species: Sw	**Number of trees (20 m x 20m)**58		

Notes: Lots of dead dogwood. Upslope from N and E sampling locations is Jack Pine

DBH (cm) Sw	Sw: 11.5, Sw: 8.3, Sw: 9.9, Sw: 9.6, Sw: 11.8, Sw: 13.1, Sw: 11.2, Sw: 7.4, Sw: 14.5, Sw: 13.8, Sw: 14.4, Sw: 11.9

Understory	**N:** Moss (knights plume),	**E:** wild strawberry, aster cilliolatus, 2 mosses(?)	**S:** same two mosses as E, blue columbine	**W:** 2 mosses (same as E), dandelion, blue columbine	**Around the site:** prickly rose, rubus idaeus, grass	**Dominant understory:** Moss (Pleurozium schreberi), blue columbine (Aquilegia brevistyla), Lindley's aster

Ground cover (1 m by 1 m) — **Ground cover (%)**

	lichen	*moss*	*leaf litter*	*needles*	*bare soil*	*CWD (twigs)*	*live*	*shrubs*	Sampling distance to neartest tree (Sw)
NE	0	1	0	100	0	8	1	0	N: 100cm
SE	0	5	0.5	100	0	16	6	0	E: 24cm
SW	0	3	6	100	0	2	4	0	S: 30cm
NW	0	15	2	95	0	5	15	0	W:32cm
Site Average	0	6	2.125	98.75	0	7.75	6.5	0	

Site and Soil Assessment Form			**Observers: Cassandra, Brittany**				
Slope (%): N: -10% , 6° S: -37%, 20.5° E: -10%, 6° W: -39%, 21.5°		Aspect (deg): NE facing	Slope position: Flat		Reclaimed		
July 20,2015		**Site 15**	**N: 57.02367 W: -111.49973**				
Tree species: Sw, Pj, Bw	**Number of trees (20m x 20m):** 40						
DBH (cm): Sw	11.3, 15, 4.7, 10.8, 12.3, 11.2, 6.5, 11.1, 15.8, 10.7, 17.3, 15.9, 13.4, 15.0, 15.6, 15.0, 14.7, 11.8, 11.9, 14.4, 11.8, 14.0, 10.3, 10.8, 14.3, 15.1, 11.0,						
DBH (cm): Pj	Pj: 8.7 Pj: 10.7, Pj: 9.3, Pj: 9.8, Pb: 3.5, Pj: 9.3						
DBH (cm) Pb	Bw: 4.0, Bw: 1.5, Bw: 2.0, Bw: 6.1,						
Understory	**N:** wild strawberry, rasberry, grass, dandelion, unknown fern, moss	**E** wild strawberry, raspberry, dandelion, moss, lichen	**S:** prickly rose, moss, wild strawberr y, unknown	**W:** Wild strawberry, baby Aw, rubus idaeus, moss, danelion,	**Dominant understory:** Fern spp, wild strawberry, moss		**Sampling distnace to nearest tree (Sw):** N: 110 cm E: 130 cm S: 90 cm W: 98 cm
Ground cover (1 m by 1 m)			**Ground cover (%)**				

	lichen	*moss*	*leaf litter*	*needles*	*bare soil*	*CWD (twigs)*	*live*	*shrubs*
N	0	0.5	6	100	0	2	12.5	1
E	0.50	5	6	100	0	2	20	3
S	0	5	2	100	0	3	7	2
W	0	53	20	60	0	8	67	9
Site Average	0	15.875	8.5	90	0	3.75	26.625	3.75

Site and Soil Assessment Form		**Observers: Cassandra, Brittany**			
Slope (%): N: -5% , 3° S: +2%, 1.0° E: -5%, 3° W: -11%, 6°	Aspect (deg): W, 270°	Slope position: Upper	Reclaimed		
July 20,2015	**Site 16**	**N: 56.99092 W: -111.53693**			
Tree species: Sw	**Number of trees (20m x 20 m):** 66				
DBH (cm) Sw	5.4, 7.5, 6.5, 6.1, 4.2, 2.6, 5.2, 1.1, 8.7, 6.2, 4.3, 5.2, 6.6, 6.8, 1.9, 7.0, 6.7, 5.2, 5.6, 7.3, 6.2, 4.0, 0.7, 2.9, 1.0, 4.4, 5.7, 2.8, 6.3, 3.5, 2.4, 5.4, 3.8, 5.9, 7.0, 5.9, 4.4, 4.9, 5.4, 7.3, 6.6, 5.5, 7.5, 5.7, 6.0, 5.6, 9.1, 3.0, 2.8, 6.6, 5.1, 3.4, 8.9, 5.1, 6.4, 6.6, 8.9, 5.5, 6.1, 5.8, 6.0, 5.5, 6.1, 5.8, 6.0, 5.5, 3.0, 6.3, 4.9, 10cm from ground: 4.8				
Understory	**N:** Wild strawberry, whitet sweet clover, dandelion, fireweed, alsike clover, grass, mushrooms, unkown moss (glowmoss?), unkown lichen	**E:** alfalfa, dandilion, mushrooms, same two mosses as N	**S:** Wild smooth strawberry, fireweek, mushroom, alsike clover, frogpelt, mosses, stair-step moss, pleuroium schreberi tonetypnum	**W:** wild strawberry, dandelion, fireweed, alfalfa, clover, mushroom, mosses	**Dominant understory:** Moss, wild straw, alfalfa (Medicago
Ground cover (1 m by 1 m)	**Ground cover (%)**				**Sampling distance to nearest tree (Sw)** N: 64cm, E: 50cm, S: 56cm, W: 73cm

	lichen	*moss*	*leaf litter*	*needles*	*bare soil*	*CWD (twigs)*	*live*	*shrubs*
1	2	92	16	6	1	0	112	0
2	1.00%	98	24	1	0.5	1	103	0
3	2.5	98	24	3	0	0	100	0
4	1	98	20	2	2	0	108	0
Site Average	0	96.5	21	3	0.875	0.25	105.75	0

Site and Soil Assessment Form		Observers: Cassandra, Brittany	
Slope (%): N: -1% , 0.5° S: -1.5%, 1.0° E: 0%, 0° W: -5%,	Aspect (deg): E, 101°	Slope position: Flat	Reclaimed
July 20,2015	**Site 17**	**N: 56.99222 W: -111.53276**	
Tree species: Sw, Pb		**Number of trees (20 m by 20 m): 44**	

DBH (cm) Sw	9.8, 8.7, 7.5, 3.7, 6.4, 5.8, 11.7, 13.1, 9.4, 2.9, 2.8, 10.4, 2.4, 2.4, 9.5, 8.7, 10.2, 11.3, 9.7, 6.8, , 1.7, 5.5, 7.4, 5.7, 4.0, 6.9, 7.4, 10.7, 7.0, 4.8, 8.8, 10.3, 8.4, 9.3, 7.7, 6.7, 13, 4.2, 8.8, 10.0, 3.0, 6.2, 9.8

Understory	**N:** dandelion, clover (purple), alfalfa, wild red raspberry, wild smooth strawberry, fireweed, moss [stairstep]	**E:** dandelion, alsike clover, fireweed, wild red raspberry, mosses (2)	**S:** Wild smooth strawberry, alfalfa, fungi/mushrooms, vetch spp., dandelion, 2 mosses (unknown)	**W:** white sweet clover, dandelion, fireweek, alsike clover, mosses (2-	Dominant understory: Moss (Pleurozium schreberi), Wild strawberry, Dandelion	Sampling distance to nearest tree (Sw) N: 70cm E: 70cm S: 119cm W: 80cm

Ground cover (1 m by 1 m) **Ground cover (%)**

	lichen	*moss*	*leaf litter*	*needles*	*bare soil*	*CWD (twigs)*	*live*	*shrubs*
1	0	88	2	11	0	5.5	89	0.5
2	0.00%	100	24	1	0	0	124	1
3	0.5	79	24	0.5	10	0.5	97	0
4	0	77	18	0	4	0	97	0
Site Average	0.125	86	17	3.125	3.5	1.5	101.75	0.375

Site and Soil Assessment Form	Sumr	Observers: Cassandra, Brittany	
Slope (%): NE: -27% , 15° SE: -25%, 14° NW: -27%, 15° SW: -25%, 14°	Steep slope: Mid	**Reclaimed**	
July 19,2015	**Site 18**	**GPS Coordinates: N:56.99769 W: -111.53362**	
Tree species: Sw, Aw	**Number of trees (20 m x 20 m): 79**		

DBH (cm) Sw:	7.5, 9.9, 11.5, 9.9, 8.9, 7.4, 6.0, 7.6, 5.6, 7.3, 10.4, 7.4, 0.4, 6.2, 5.7, 7.7, 10.0, 10.0, 9.2, 7.7, 9.8, 11.8, 9.2, 8.5, 9.1, 10.6, 6.0, 2.5, 8.8, 7.2, 6.0, 5.5, 11.4, 8.3, 10.5, 8.8, 8.8, 11.5, 9.7, 9.6, 7.0, 6.8, 6.0, 5.7, 9.8, 11.3, 10.9, 6.1, 11.7, 10.4, 13.5, 9.0, 8.3, 9.8, 11.4, 7.7, 11.7, 9.0, 10.2, 9.4, 9.4, 5.7,9.2, 11.5, 7.5
DBH (cm)	Aw:9.1, Aw:3.5, Aw:7.0, Aw:7.6, Aw:9.2, Aw:7.2, Aw:7.5, Aw:7.8, Aw:3.4, Aw:4.7, Aw:4.3, Pb:5.4,

Understory	**NE:** blue columbine, dandilion, many mosses, many lichen, Jameson liverwort	**SE:** Unknown moss	**SW:** same as SE	**W:** moss	**Dominant understory:** Moss (Pleurozium schreberi), Lichen (Leptobryum pyriforme),	Sampling distance to nearest tree (Sw) NE: 71cm, SE: 47cm, SW: 67cm, NW: 77cm

Ground cover (1 m by 1 m) **Ground cover (%)**

	lichen	*moss*	*leaf litter*	*needles*	*bare soil*	*CWD (twigs)*	*live*	*shrubs*
NE	3.5	82	2	32	0	1.5	85	0
SE	0	60	13	98	1	11	6	0
SW	0	8.5	60	92	0.5	4	8.5	0
NW	0	3	34	98	0	7	3	0
Site Average	0.875	38.375	27.25	80	0.375	5.875	25.625	0

Site and Soil Assessment Form

Site and Soil Assessment Form		**Observers: Cassandra, Brittany**	
Slope (%): NE: -29% , 16° SE: -28%, 15° NW: -28%, 15.5° SW: -29%, 17°	Aspect (deg): N,0°	Slope position: Mid	**Reclaimed**
July 19,2015	**Site 19**	**N: 56.99865 W: -111.54722**	
Tree species: Sw, Pb, Aw	**Number of trees (20m x 20m): 54**		

DBH (cm) Sw	12.3, 12.5, 7.0, 7.5, 4.5, 17.5, 13.7, 15.8, 11.6, 16.6, 13.8, 16.1, 14.0, 14.6, 14.7,
DBH (cm) Pb	Pb: 7.4, Pb: 5.4, Pb 13.7, Pb:3.1, Pb:1.5, Pb:3.7, Pb:5.7, Pb:2.3, Pb:2.3, Pb:6.3, Pb:6.3, Pb:5.6,
dbh (cm)	Aw:10.0, Aw:1.7, Aw:6.1, Aw:4.3, Aw:2.7, Aw:2.5, Aw:2.5, Aw:5.8

Understory	**NW:** prickly rose, wild smooth strawberry, aspen, lichen (2), moss(1), red osier dogwood	**SE:** unknown moss (1)	**NE:** fireweed, wild smooth strawberry, grass, aspen, stairstep moss, lichen (2), unkown moss	**SW:** aspen, clover, wintergreen unknown	**Dominant understory:** Moss, lichen (Peltigera spp.), Common pink wintergreen (Pyrola asarifola)	Sampling distance to neartest tree (Sw) NE: 116cm, SE: 109cm, NW: 116cm, SW: 60cm

Ground cover (1 m by 1 m) — **Ground cover (%)**

	lichen	*moss*	*leaf litter*	*needles*	*bare soil*	*CWD (twigs)*	*live*	*shrubs*
NW	5	4	4	98	0	3	8	0
NE	40	45	11	25	0	7	87	0
SE	0	6	31	100	0	10	6	0
SW	0.5	8	29	100	0	7	12.5	0
Site Average	11.375	15.75	18.75	80.75	0	6.75	28.375	0

Site and Soil Assessment Form

Site and Soil Assessment Form		**Observers: Cassandra, Brittany**	
Slope (%): N: -24% , 14° E: -25%, 14° S: -30%, 17° W: -30%, 17°	Aspect (deg): N,0°	Slope position: Mid - Upper	Reclaimed
19-Jul-15	**Site 20**	**N: 56.99837 W: -111.54800**	
Tree species: Aw	**Number of trees (20m x 20 m): 69**		

dbh (cm)	2.2, 0.9, 7.7, 10.1, 2.0, 3.3, 3.2, 2.9, 11.6, 15.6, 1.1, 1.6, 4.7, 4.5, 1.1, 0.8, 7.6, 6.4, 0.8, 2.0, 2.9, 1.6, 2.3, 1.2, 3.8, 0.8, 1.9, 0.8, 2.2, 1.2, 3.8, 2.9, 7.7, 11.1, 1.6, 2.3, 3.8, 8.4, 6.5, 2.1, 1.8, 1.4, 1.6, 5.0, 1.2, 1.4, 2.2, 2.5, 6.3, 9.4, 3.3, 5.3, 1.0, 3.5, 4.3, 1.1, 1.3, 7.4, 7.0, 1.1, 7.4, 6.3, 2.2, 0.7, 3.7, 3.7, 1.5, 2.1, 13.4, 2.9, 11.1, 2.5

Understory	**N:** White sweet clover, alsike clover, prickly rose, grass, moss, unkown wintergreen [common pink],	**E:** white sweet clover, wild strawberry, stairstep moss	**S:** alsike clover, grass, moss	**W:** buffaloberry, alsike clover, red-osier dogwood	**Dominant understory:** Grass (Fescue spp.), Moss (Pleurozium schreberi), Alsike clover (Trifolium hybridum)	**Sampling distance to neartest tree (Aw)** N: 36cm, E: 66cm, S: 72cm, W: 101cm

Ground cover (1 m by 1 m) — **Ground cover (%)**

	lichen	*moss*	*leaf litter*	*needles*	*bare soil*	*CWD (twigs)*	*live*	*shrubs*
N	0	12	72	0	0	10.5	23	2
E	0	72	22	0	0	4	75	0
S	0	14	78	0	0	10.5	25	0
W	0	1.2	100	0	0	8.5	6.5	1.5
Site Average	0	24.8	68	0	0	8.375	32.375	0.875