University of Alberta

EARLY ECOSYSTEM GENESIS USING LFH AND PEAT COVER SOILS IN ATHABASCA OIL SANDS RECLAMATION

by

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ABSTRACT

Peat mineral soil mix has been the predominant cover soil used in Athabasca oil sands reclamation. Use of LFH mineral soil mix (forest litter layers and underlying mineral soil) has recently been mandated by regulatory approvals. Effectiveness of these cover soil types to provide diverse, native plant communities long term was compared at four research sites four to thirteen years of age. LFH mineral soil mix produced significantly greater woody plant density, vascular plant species richness, native species richness, total cover and native species cover; peat mineral soil mix had significantly higher non-native (weed) species cover. Species composition, growth form assemblage and dominant species differed between cover soils. LFH mineral soil mix is a superior cover soil to peat mineral soil mix for native plant community development. Patches of bare soil on both cover soils had significantly different soil chemical and physical properties than soil at patches of diverse vegetation.

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1. BACKGROUND

Oil sands mining occurs on a very large scale in north eastern Alberta, Canada (Figure 1.1). Timber and natural soil horizons are salvaged and stockpiled before massive trucks and shovels are used to excavate the underlying overburden and remove oil sands for extraction and upgrading (Alberta Energy 2013). Following mining, disturbed ecosystems must be reclaimed and soil and site conditions must be established to facilitate development of desired plant communities. Operators in the Athabasca oil sands region operators must construct self sustaining, locally common, boreal forests (Alberta Environment 2007a, 2007b, 2007c, 2007d, 2009, 2011), which requires replacement of boreal forest vegetation and establishment of hydrologic flows, biogeochemical cycling and other ecosystem functions (Johnson and Miyanishi 2008).

Oil sands extraction in Alberta provides 99 % of Alberta's proven oil reserves, accounting for 13 % of global oil reserves (Government of Alberta 2013a). In northern and eastern Alberta, approximately 169.3 billion barrels of recoverable resources underlie 142,200 km^2 (Government of Alberta 2013b, 2013c) (Figure 1.1). Of these deposits, 20 % are within 75 m of the surface and recoverable by surface mining; 80 % can be extracted in situ with methods such as cyclic steam stimulation and steam assisted gravity drainage, using wells and pipelines similar to conventional oil drilling (Government of Alberta 2013c*).* In situ methods extract bitumen and sand is left underground, eliminating the need for tailings ponds and leaving a smaller footprint. To date 715 km^2 have been disturbed by oil sands mining, 0.16 % of Alberta's boreal forest.

To improve reclamation success, surface mine plans worldwide now salvage ecosystem components such as upper soil profile layers, greatly facilitating revegetation by providing a suitable growth medium and a potential source of plant propagules. In many countries, revegetation now focuses on use of native species (Alberta Environment 2010, Bell 2001) to create an ecosystem similar to that which existed prior to disturbance, that is adapted to local conditions and can theoretically adapt to a changing climate (Choi et al. 2008).

Oil sands reclamation prescriptions have traditionally used various depths of cover soil (typically peat mineral soil mix) and subsoil to cap less suitable overburden or waste materials. Application of salvaged litter layers (LFH) and upper soil horizons from upland boreal forests (collectively called upland surface soil) has recently proven to be an important source of native plant propagules leading to development of plant communities with higher cover, richness and diversity in the first few years relative to traditional peat mineral soil mix covers (Mackenzie 2006, Mackenzie and Naeth 2010, Mackenzie 2012). Government guidelines and approvals now require use of upland surface soil in oil sands reclamation (Alberta Environment 2007a, 2007b, 2007c, 2007d, 2009, 2010, 2011). Traditional prescriptions and use of upland surface soil, termed LFH mineral soil mix once placed (Naeth et al. 2013), create different abiotic conditions or starting points for ecosystem development; resulting plant communities and soils may develop with different trajectories.

This research investigated early plant community development and soil-plant relationships at sites of different ages amended with LFH mineral soil mix or peat mineral soil mix in the Athabasca oil sands region. Sites were four to thirteen years of age, to determine longer term impacts of the cover materials.

2. LITERATURE REVIEW

2.1 Plant Communities

Plant ecologists have been discussing the concept of plant communities since the early 20th century and despite a century of work and countless papers on the subject a consensus is not apparent. According to van der Maarel and Franklin (2013), most agree that a plant community is a relatively uniform area of vegetation with a recognizable floristic composition and structure that is relatively distinct from surrounding vegetation. Populations of species that make up the community, while distributed individualistically in the landscape, likely interact within the community and become an integrated unit with emergent properties. In contrast, vegetation can be defined much more simply as “a system of largely spontaneously growing plants”, which excludes crops and plantations from the definition (van der Maarel and Franklin 2013).

2.2 Plant Community Organization

A complex framework of factors influences plant community organization. The main drivers that determine species composition can be grouped as landscape factors, local site conditions or vegetation related effects. These factors operate at different scales with the superimposed effect of stochasticity or chance.

Novak and Prach (2003) found that mean annual temperature and precipitation were important variables in succession of naturally recovering basalt quarries. Dispersal constraints and dispersal distance were key to recovery (Prach 1987, Ash et al. 1994, Wiegleb and Felinks 2001a, Walker and del Moral 2008, Suding et al. 2004). Novak and Prach (2003) described 30 m as a critical distance for dispersal from surrounding areas. Kirmer et al. (2008) found that 17 km was a critical distance for colonization of open cast mines from surrounding areas. They suggested that regional species pools, rather than dispersal distance, best explained plant community variances. Weigleb and Felinks (2001a) discussed this concept for post mining landscapes, referring to regional species pools as neighbourhood effects. Landscape factors (specifically macroclimate and nearby propagule sources) explained more variability in plant communities than local factors (soil physical properties, pH) (Rehounková and Prach 2006).

Local site conditions, which operate on a much smaller scale than landscape factors, can play an important role in plant community development. Several researchers identified edaphic conditions and substrate quality as important parameters. Prach (1987) discussed the influence of hydrologic conditions on germination and pre-reproductive mortality. Rehounková and Prach (2006) identified water table depth as the most important soil physical parameter. Craw et al. (2007) found that revegetation success on waste rock piles with no cover soil in New Zealand was determined by substrate physical properties, with cohesion, water content and proportion of quartz pebbles being important.

Harsh soil conditions can prevent species common to the area, and capable of dispersing onto the site, from surviving (Ash et al. 1994). Martinez-Ruiz and Marrs (2007) studied succession on uranium mine wastes and found that quality of initial substrates impacted successional trajectories. High fertility can alter species composition positively (Rowe et al. 2006) or negatively (Walker and del

Moral 2008). Light availability and soil nitrogen, although less important than the regional species pool, were significant factors in species occurrence on mined sites (Kirmer et al. 2008). Wiegleb and Felinks (2001a, 2001b) classified physical and chemical properties as sorting effects (filter) that play an early development role but does not control plant community development. Aspect and weather can also be important local site conditions. Martinez-Ruiz and Marrs (2007) found aspect affected revegetation on uranium wastes and vegetation developed more quickly on favourable than harsher substrates. Spring weather was important during the seedling phase (Prach 1987, Wiegleb and Felinks 2001a).

On five to seven year old sites in Germany Weigleb and Felinks (2001b) found environmental parameters and plant community age did not completely explain observed variances and concluded that analyses should include spatial aspects and reclamation practices. Kirmer and Mahn (2001) found that substrate affected reclamation method; grass clippings from local natural grasslands accelerated succession on hospitable sites, but had little effect on harsher sites (lower pH and sand content). In reclaimed quarries in Spain, plant communities on sewage sludge and controls did not converge after five years; most species on both were ruderal (Moreno-Penaranda et al. 2004). Fertilizer application favoured weeds over native species and altered successional trajectories (Walker and del Moral 2008). Norman et al. (2006) found species composition differed on seeded and unseeded sites after bauxite mine reclamation in Australia.

The third category of factors affecting plant community organization is what Weigleb and Felinks (2001b) called “strategies of colonizing species” in their conceptual model of early succession mechanisms. Others discuss specific strategies of most importance in plant community development. Germination and establishment probabilities of seeds that arrive and/or are present at a primary or secondary site are influential (Wiegleb and Felinks 2001a). Walker and del Moral (2008) proposed germination requirements, response to fertilizer, tolerance to herbivory and disease, competitive abilities, and ability to protect and facilitate desirable species as important traits. Kirmer et al. (2008) found that terminal velocity of seeds, wind dispersal and bird dispersal were important, although less so than the regional species pool. Trade offs species make in relation to main environmental constraints (access to disturbed site, availability of soil resources, availability of light, sources of mortality such as herbivores and pathogens) are important, and trade offs vary with habitat (Tilman 1990).

Initial vegetation to establish at a newly developing site can be critical. The pre-emptive initial floristics model states that species present at the beginning direct the course of succession but are not the only species with considerable cover (Wiegleb and Felinks 2001a). Norman et al.'s (2006) work supports the original initial floristics composition model proposed by Egler (1954) which proposes that the overall pattern of development is influenced by species composition that first establishes and thereafter changes are only in the relative abundance of species. A similar concept is assembly theory as described in Young et al. (2001) which describes priority effects. The first species to arrive have priority, and strength of this priority depends on arrival time and on species traits after arrival.

The regeneration niche concept (Grubb 1977) comes into play in early plant community development, and describes how species can co-exist as adults when they are the same life form with the same habitat requirements and phenology. Their co-existence and the maintenance of species rich communities is related to differences in regeneration niches and that species differ in responses to the environment based on their life history stage. Examples of differentiation in the regeneration niche include production of viable seed (flower and fruit production methods), dispersal strategies (space vs time), germination cues, establishment requirements (substrate needs) and development of immature plants.

The final subcategory of vegetation related effects is biotic interactions, occurring once plants become established. Interactions such as competition (Prach 1987), facilitation and inhibition (Wiegleb and Felinks 2001a) become important later; Prach (1987) estimated 15 years after initiation. Walker and del Moral (2008) posit that facilitation and inhibition are more prominent later due to increased physical stability and fertility. Gomez-Aparicio (2009) found that positive and negative effects of neighbour plants depended on life forms and plant performance estimators; positive effects were seen early on emergence and survival and negative or neutral effects were seen later on growth and density.

No discussion of plant community development is complete without mentioning succession. What began as a theory describing flow of one group of species to another (nudation, migration, ecesis, competition, reaction, stabilization and climax of Clements 1916) became a broad and complex web of many models and concepts including the individualistic concept (Gleason 1917), facilitation, tolerance and inhibition models (Connell and Slatyer 1977), resource ratio (Tilman 1985, 1990), state and transition models (Westoby et al. 1989, Lockwood and Lockwood 1993, Allen-Diaz and Bartolome 1998), the carousel model (van der Maarel and Sykes 1993), and the directional species replacement concept (Platt and Connell 2003), to name a few. More recently assembly rules and priority effects (Keddy 1992, Lockwood 1997, Weiher and Keddy 1999) have come to the fore with a similar view to understand how communities form (Young et al. 2001). Community assembly rules are filters that act on regional species pools to determine local community structure and species composition (Keddy 1992, Holdaway and Sparrow 2006). Van der Maarel and Franklin (2013) and Young et al. (2001) provide comprehensive reviews of most of these concepts.

2.3 Species On Early Succession Sites

Plant community studies on early succession often include species present, types of species and how they change over time. Prach (1987) studied life history traits and found annuals and biennials dominated in the first years then were replaced by perennials after 15 years. After 15 years shrubs accounted for 10 % of cover, with few changes between 15 and 30 years due to early unfavourable abiotic conditions and later competition with forbs. In contrast Wiegleb and Felinks (2001b) found no general trend in dominant life form at 5 to 70 year old post mining, primary succession sites. Gomez-Aparicio (2009) examined reclamation treatments and found neighbour plant effects differed with life form. Forbs as neighbours had negative effects on target species, especially grasses, while shrubs had positive effects. Forbs were negatively affected by neighbour plants (sensitive to competition) while trees were positively affected.

Plant communities on early succession sites vary with dispersal mechanisms. Kirmer and Mahn (2001) studied plant communities with and without reclamation (grass clippings) and found that after six years hospitable sites (pH 4 to 5, high sand content) had a significant proportion of wind dispersed species relative to less hospitable sites (pH < 3, lower sand content) where wind dispersed species were rare and only species seeded from grass clippings were found. At primary and secondary succession sites in Czech Republic animal and wind dispersed species increased in the first 10 years (Prach 1997). At 5 to 70 year old naturally recovering post mining sites in Germany no dominant dispersal mechanisms were observed (Wiegleb and Felinks 2001b). Martinez-Ruiz and Marrs (2007) found no dispersal mode replacement sequence in 21 years on uranium mine waste after hypothesizing animal dispersal would replace wind dispersal.

Soil seed banks are an important aspect of dispersal. After bauxite mining in Australia with no seeding, Norman et al. (2006) found native and exotic ephemerals, reflecting the seed bank dispersal of species on the site. Reclaimed sites had fewer sprouting species than natural forests. At primary and secondary succession sites in the Czech Republic species with heavier propagule weights and those forming persistent seed banks decreased with time (Prach 1997).

Rehounková and Prach (2006) studyied gravel pits and classified species as generalists or specialists. Generalists (typically ruderals) were found on young seral stages in dry sites; more specialized wetland species appeared in wet and flooded sites of the same age. On reclaimed coal mine sites later successional species were typically present in the first three or four years on suitable sites, but with low cover which is likely related to germination and seedling development constraints (Prach 1987). In another post mining study adding grass clippings led to a species rich, later successional community after six years, while controls were dominated by pioneer sandy grassland species (Kirmer and Mahn 2001).

Similar trends in Grime's C-S-R strategies were found on natural recovery sites. Prach (1987) found that ruderals and stress tolerant ruderals were replaced by competitive ruderals on primary and secondary succession coal mines. He found competitors increased the first ten years, ruderals declined and stress tolerant species showed no trend. Weigleb and Felinks (2001b) found that most species on 5 to 70 year old sites were competitors or stress tolerant competitors, trending towards competitors. With reclamation, specifically fertilizers or fertilizer type amendments, results were conflicting. Rowe et al. (2006) found fertilizing primary succession sites favoured species of drier habitats and competitive, dominant species and disadvantaged less competitive ruderals. In limestone quarries, sewage sludge did not increase ruderality (Moreno-Penaranda et al. 2004). With grass clippings ruderality declined at post mine sites (Kirmer and Mahn 2001).

Raunkier’s classification was used to examine trends in types of species in some studies. At primary and secondary succession sites over the first 10 years phanerophytes (perennating bud on upright stems well above soil surface) increased, therophytes (annual plants that survive unfavourable conditions as seed) declined with no trends for geophytes (perennating buds below soil surface, also called cryptophytes) and hemicryptophytes (perennating bud at soil surface) (Mueller-Dombois and Ellenberg 1974, Prach 1997). Weigleb and Felinks (2001b) found that hemicryptophytes dominated 5 to 70 year old sites; therophytes were of minor importance, reaching 10 and 5 % cover in pioneer stands and seeded grasslands, respectively. Martínez-Ruiz and Marrs (2007) found therophyte to hemicryptophyte replacement only on poor substrates.

2.4 Boreal Understory Plant Community Organization

Boreal forests go through four development stages: stand initiation, stem exclusion, canopy transition and gap dynamics (Chen and Popadiouk 2002). Stem initiation begins after disturbance and continues until the canopy is fully formed. Stem exclusion continues from a fully formed canopy and ends when shade tolerant conifers reach the canopy. Canopy transition starts when shade intolerant species begin to die and are gradually replaced by shade tolerant tree species. Gap dynamics is reached when the system is at steady state with a balance between regeneration and mortality. The focus in this thesis is on stand initiation, but there will be some discussion of dynamics in later stages to better understand why certain species are present in certain forest types, because the forest surrounding a disturbed site is a source of propagules.

Several factors affect stand trajectory during stand initiation; the first being disturbance type and severity. The main disturbance in boreal forest is fire, although insect outbreaks and human disturbances including harvesting and fragmentation can be very destructive. Other factors can be grouped into two filters. The first filter is the regional species pool and how it relates to propagule availability on disturbed sites. Pre-disturbance and nearby communities that form the pool are mainly affected by regional/local conditions and overstory-understory relationships. The ability of species in the pool to disperse to the disturbed site is another component of this filter. The second filter is whether species that reach the site survive, which is affected by regeneration microsites and initial site conditions. Stochasticity is superimposed, particularly affecting disturbance, dispersal events, seed rain, and creating weather conditions that impact survival.

2.4.1 Disturbance type and severity

Important disturbance parameters impacting post disturbance communities are time of year (Zasada et al. 1992, Chen and Popadiouk 2002), spatial features of disturbance (Greene et al. 1999, Roberts 2004), return time (Greene et al. 1999, Roberts 2004), specificity (Greene et al. 1999) and severity (Greene et al. 1999, Roberts 2004, Rydgren et al. 2004). Specificity refers to affected species and severity refers to affected forest layers. Roberts (2004) separated effects into three strata (canopy, forest floor and soil, understory vegetation) that could be disturbed by different fire severities. If the canopy is removed, competition with higher strata is reduced, the understory is released and competition increases within it; microclimate is altered by solar radiation, increased temperatures and temperature fluctuations, lower relative humidity and surface soil water. Canopy removal can provide coarse woody debris substrate. If the forest floor and soil are affected, resulting pits, mounds and mineral soil substrates are important as most species favour mineral soil seed beds and are inhibited by thick needle or litter layers. Understory damage occurs through direct damage to plants and altered propagule availability (mainly root and rhizome bank). Damage to the forest floor and soil can destroy seeds and propagules in the seed bank.

Conditions of the post fire environment include a black surface due to ash and vegetation loss, which increases temperatures and speeds litter decomposition and nutrient flushes (Chen and Popadiouk 2002). Relative humidity decreases and soil water is altered. Dry sites become drier with higher temperature and wind; poorly drained sites become wetter due to lower evapotranspiration. Post fire seed bed depth is reduced leading to better access to water for seeds and exposure to toxicity from ash (Kemball et al. 2005). Ash affects soil wettability, porosity and pH. After two years establishment increased on burned sites relative to unburned or lightly burned sites due to shallow depth to mineral soil and high moss cover creating damp conditions. Post fire seed bed effects last five to seven years after which there is too much litter and moss (Bonan and Shugart 1989, Greene et al. 1999).

Harvesting and fire do not result in the same site conditions. Increased soil resources in harvested stands are shorter lived with no ash or activated carbon (Hart and Chen 2006). Both disturbances increase understory diversity, although wildfires increase it more substantially. Post logging understory communities are more similar to pre-disturbance communities than post fire communities; there are more late successional species and a notable absence of pioneer species. Communities from fire and logging tend to converge after 20 years.

Post mining environments differ from post fire or post harvesting environments. Like an intense fire, the post mining environment is often missing a seed bank and the seed bed has higher temperatures due to vegetation loss, but no ash is present. Higher temperatures can release nutrients if there is organic material in the cover soil and microbial communities to decompose it. The only similarity to post harvesting environments is compaction due to heavy machinery, and use of upland surface soil as a cover can introduce a seed bank and microorganisms.

2.4.2 Pre-disturbance communities

Variation in understory species composition in undisturbed forests, aside from site initiating factors, is affected by canopy composition (dominant), regional and local site conditions and longitudinal and latitudinal factors (Hart and Chen 2006). The canopy-understory relationship has been called a linkage rather than a feedback due to parallel responses of both strata to similar environmental gradients (Gilliam and Roberts 2003). In practice 75 % of understory species did not show specificity for a single canopy type (De Grandpre et al. 2003). Specificity may only reflect similar responses to a particular disturbance regime. Understory species may be restricted by specific abiotic conditions instead of a specific canopy type, although biotic conditions are modified by canopy type.

Despite wide understory species tolerances and lack of exclusivity, strong associations of canopy type and understory composition occur at stand level (Hart and Chen 2006, Macdonald and Fenniak 2007, Chavez and Macdonald 2010) from different effects of conifer and broadleaf trees. Conifer stands have lower light transmission, soil temperature, soil nutrients, pH, litter depth and litter quality (Hart and Chen 2006, Macdonald and Fenniak 2007), thus broadleaf forests have higher herbaceous plant diversity (Hart and Chen 2006). These forests favour vascular plants and inhibit mosses and lichens (Macdonald and Fenniak 2007); there are more shrubs and shade intolerant herbs (Chavez and Macdonald 2010). Conifer forests have lower herbaceous plant diversity, higher bryophyte diversity (Hart and Chen 2010) and more low nutrient demanding, shade tolerant species (Chavez and Macdonald 2010). Mixedwood forests have shade tolerant and nutrient demanding, shade intolerant species. Composition of mixedwood and conifer forests is similar (Macdonald and Fenniak 2007).

Regional and local site conditions help shape understory composition. Bonan and Shugart (1989) emphasized the importance of soil water in segregating forest communities. Through water and nutrient gradients, slope position and surficial geology affect species diversity, richness and evenness (Chipman and Johnson 2002). Glaciofluvial sites, with more nutrients, had greater diversity than glacial till sites with fewer. Upper slopes, with less water, were more diverse than down slope sites with more water. Frelich et al. (2003) found soil depth, nitrogen and light affected species composition. Sites with shallow soil, high light and high nitrogen mineralization had moss communities. Sites with average to deep soil and average to high nitrogen mineralization could have two different communities depending on light levels. A third group of understory species was associated with deep soils, low nitrogen mineralization and *Pinus strobus* L. (white pine) and *Betula papyrifera* Marsh. (paper birch) canopy species.

Latitude and longitude affect undisturbed forest species composition. The main latitudinal effects are solar radiation, temperature and permafrost (Bonan and Shugart 1989, Hart and Chen 2006). Solar radiation is lower in northerly regions, and its effects are also exerted through sun angle, which plays a greater role at higher latitudes, creating different shading patterns (Bonan and Shugart 1989). Lower temperatures at higher latitudes reduce decomposition of organic matter and nutrient cycling. Low temperatures and permafrost, which maintain higher soil water, can be important, for example, directing the location of the treeline in Russia. Fewer deciduous species at higher latitudes result in reduced nutrient cycling, decreasing understory resource heterogeneity, and loss of associated understory species (Hart and Chen 2006).

Longitudinal differences exist across the boreal forest, most importantly, with increased precipitation moving eastward, and thus a longer fire return cycle (Hart and Chen 2006). This gradient creates a zone in the central boreal with an intermediate fire cycle relative to a short fire cycle in the western boreal and a long fire cycle in the eastern boreal. As the intermediate disturbance hypothesis suggests, the central boreal has higher species diversity. This higher diversity might also be related to higher overstory species diversity in the central boreal. While overstory species from the western boreal (*Populus tremuloides* Michx. (trembling aspen) and *Pinus banksiana* Lamb. (jack pine)) are missing in the east, and *Abies balsamea* (L.) Mill. (balsam fir) from the eastern boreal is less abundant in the west, all three species are present in the central boreal.

2.4.3 Species strategies to occupy disturbed sites

Grubb's (1977) regeneration niche concept applies to the boreal forest. Boreal species often have similar niches as adults, but different niches during regeneration. Grubb discusses the major ways that plant species differ in their regeneration niche and some of these affect which species will occupy disturbed sites, namely production of viable seeds and dispersal in space and time.

Species life history traits interact with disturbance severity to determine post fire communities (Ramovs and Roberts 2005). Life history traits related to strategies to occupy disturbed sites are likely most relevant, such as serotinous and non-serotinous cones (Chen and Popadiouk 2002), dispersal syndromes (Zasada et al. 1992) and propagule characteristics (seeds, rhizomes, other vegetative reproduction). Greene el al. (1999) described a recruitment model focusing on tree recruitment and prediction of regeneration density, but most factors could be applied to understory species. Five biotic factors in the model are basal area (proportional to seed production, asexual bud production and dispersal), seed mass (inversely proportional to annual seed production and dispersal capacity), asexual reproduction capacity, dormant seed bank capacity and shade tolerance.

Archibold (1979) and Whittle et al. (1998) found 65 to 85 % of emergents after wildfires were from seed and 15 to 35 % from remnant roots and rhizomes. Lee (2004) surmised this ratio of seed to vegetative regeneration depends on disturbance intensity, with more intense disturbances favouring regeneration from seed banks. Lee (2004) studied seed and vegetative banks in burned and unburned patches in a *Populus tremuloides* boreal forest in western Canada and found that higher total seed abundance occurred with no burn than with light and intense burns, which had similar seed abundances. With no burn cumulative index of vegetative bank abundance was higher than for light burns, which was higher than for intense burns. Total emergent cover two years after burning also followed this pattern. Propagule burial depth is important, with different LFH consumption depths by fire yielding different species assemblages. Significantly different species assemblages in seed banks and emergent vegetation were associated with patches of different burn intensities. Species assemblages in vegetative banks from different burn intensities did not differ from each other, but differed from unburned areas. Unburned and lightly burned species assemblages were similar to the vegetative bank while assemblages on intensely burned patches were similar to the seed bank. Seed bank germinants and seed dispersers dominated early communities; vegetatively reproducing species dominated later communities. Lee's (2004) main message was that there was a different strength of association between the emergent understory and the seed bank/vegetative bank depending on disturbance intensity.

Propagule banks represent dispersal through time, although plants use many seed dispersal methods. Wind and animals disperse seeds across larger distances than rhizomes and stolons which are relatively local (Lee 2004). Campbell et al. (2003) studying milled peatlands in Quebec found that without a propagule bank in severely disturbed areas, colonization depended on immigration. A method to determine immigration potential included identifying potential colonists, quantifying source populations and applying autoecological information on maximum fecundity and dispersal by wind, water and animals. Mosses, shrubs and trees had high immigration potential, forbs had lower potential. Potential did not translate into successful colonization, suggesting local habitat suitability and establishment factors must also be examined.

2.4.4 Impact of site conditions and microsites on species survival

Once species with the necessary strategies arrive at a disturbed site, they are subject to another filter, site conditions and appropriate regeneration microsites, which determine propagule survival. Research on regeneration microsites focused on species richness and maintenance in gaps and patches through time (Grubb 1977, van der Maarel 1996, Chen and Popadiouk 2002, Chavez and

Macdonald 2010), but can apply to early development, when species richness is created, not maintained. Grubb's work on regeneration niches is a component of the species strategies filter, applying to species survival because requirements differ for germination, seedling establishment and immature plant development.

Types of regeneration microsites on a disturbed site affect which species survive and establish. There is an element of stochasticity in seeds landing in the right microsites. The most important microsite type is mineral soil. Undisturbed forest floor, which is covered in leaf litter, is a poor seedbed (Roberts 2004, Kemball et al. 2005). Since the entire disturbed site may be covered in mineral soil, specific microsites must be considered. Harper et al. (1965) found soil microtopography important since it affects the number of plants establishing from seed. Specific seed shapes and surfaces interact with soil microtopography and affect the species balance, exerting its effects through modifying seed-water relationships.

Lee and Sturgess (2001) studied impacts of downed tree microsites on understory communities, which include root throw pits and mounds, logs, stumps and leaf branch piles, and the open canopy gap left by the downed tree. The latter is not technically a microsite in disturbed contexts as the entire site is a large canopy gap. Other microsites provide benefits for new plants such as suitable substrate, nutrients, water, physical structure for root establishment and facilitation of mycorrhizal relationship establishment. Microsites decrease competition through spatial segregation of niches and tolerances (Beatty 2003).

Lee and Sturgess (2001) found that species growing on woody debris were a function of decay class. Impact on species composition was limited to log and stump surfaces. The first plants to grow on woody debris were generally lichens and moss. Once logs reached decay class four, vascular plants started to colonize logs and over time species assemblages on stumps and logs became similar to the forest floor. Large diameter logs had more species than small diameter logs. Lee and Sturgess (2001) observed some specificity for woody debris as a microsite when they compared species assemblages on woody debris and forest floor. Shade tolerant herbs and common trees were primarily associated with woody debris likely due to competitive release, whereas common grasses, shade intolerant herb species, and low and tall shrubs were primarily associated with forest floor. Brown (2010) studied woody debris as an amendment in reclamation after oil sands mining and found in the first two years woody debris increased species richness and woody plant abundance and decreased non-native species cover compared to areas without woody debris (Brown and Naeth 2014).

Lee and Sturgess (2001) did not find significant differences in species composition on pits and mounds relative to the forest floor and. This is in contrast to work by Beatty (summarized in Beatty 2003) who did find significantly different species assemblages on mounds, pits and forest floor. Other researchers found that tip-up mounds and hummocks lead to increased soil fertility and increased bryophyte richness (Hart and Chen 2006). Lee and Sturgess (2001) studied aspen forests; the nature of aspen tree fall may be different from other forests.

2.4.5 Species interactions

Once plants establish, the importance of interactions with other arriving plants increases. Species composition continues to change as these interactions occur causing some species to be out-competed; these changes were reported up to 26 years after fire (Hart and Chen 2006). As suggested by the initial floristics model, after 26 years most composition changes are shifts in relative abundance of species. The first plants to establish can impact later arriving plants. In removal experiments set in Yukon, Canada, researchers separated the effect of species composition from the effect of biomass on establishment of 12 transplanted species (Gilbert et al. 2009). Dominant species were more important than species diversity in establishment of new species. Dominant species had inconsistent effects, at times acting as competitor and at other times as facilitator.

2.4.6 Typical species on disturbed sites in boreal forests

Canopy gaps have high abundances of early succession species such as *Calamagrostis canadensis* (Michx.) Beauv. (marsh reed grass), *Epilobium angustifolium* L. ssp. *angustifolium* L. (fireweed) and *Rubus idaeas* L. (wild red raspberry) (Hart and Chen 2006, Chavez and Macdonald 2010). Early communities are dominated by shade intolerant, nutrient demanding species (disturbance adapted) (Hart and Chen 2006). Mosses and lichens are not usually a large component of post fire communities as there is too much competition and they cannot grow rapidly in response to increased resources. Moss cover is higher after harvesting than fire (Rees and Juday 2002 cited in Hart and Chen 2006). Raunkiaer's life forms, geophytes, chamaephytes (perennating buds on shoots above soil surface, generally within 25 cm) and rosette hemicryptophytes were most affected by forestry practices, with more in natural than disturbed areas (Ramovs and Roberts 2005). Protohemicryptophytes (perennating buds near soil surface) had greater abundance in plantations than undisturbed areas.

2.5 Boreal Forest Propagule Banks

The seed bank literature is extensive, with numerous studies on natural, undisturbed seed bank dynamics in soils of different ecosystems. These kinds of studies form the scientific basis for use of topsoil and litter layers in reclamation.

Early work in the boreal forest was conducted by Johnson (1975) east of Great Slave Lake in the Northwest Territories, on the boreal fringe. Eight kinds of seeds were found in 62 soil cores (10 cm diameter, 10 cm depth, including litter); seeds did not germinate in the greenhouse. Tetrazolium chloride tests showed most seeds were not viable. Given the high latitude, Johnson posited that this is consistent with poleward decreases in buried viable seed populations. Species in the seed bank were *Empetrum nigrum* L. (crowberry; 71 % of cores), *Picea* spp. A. Dietr. (spruce; 65 %), *Betula* spp. L. (birch; 39 %), *Vaccinium* spp. L. (5 %), *Corydalis sempervirens* (L.) Pers. (pink corydalis; 1 core) and three unidentified.

In northern Sweden on 16 to 89 year old *Vaccinium myrtillus* L. (whortleberry) coniferous stands, there were 239 to 763 buried viable seeds / m^2 in litter and mineral soil to 5 cm; density and stand age were not related (Granstrom 1982). Core samples were divided into litter/moss, upper humus, lower humus and associated mineral soil and charcoal. In young stands with indistinct horizons fewer subdivisions were made. At 1/5 of sampling points mineral soil below humus was sampled at 1 to 3 cm and 3 to 5 cm. In a greenhouse 15 species emerged; five not present in vegetation of the sample plot. Seed bank species were present in samples or known to be widely dispersed. Few common species in this case use a seed bank survival strategy due to long disturbance intervals.

Later work by Granstrom (1986) found densities of 100 to 29,000 seeds / m^2 in cores of litter and 6 cm of mineral soil from 43 stands. Species richness ranged from 3 to 37 with no clear geographical pattern in seed numbers or species richness, although less fertile sites had fewer species. Dominant species were *Betula* spp., *Vaccinium myrtillus*, *Rubus idaeus* and *Luzula pilosa* (L.) Willd. (hairy woodrush). Depth distribution of seeds varied with forest type; seeds in *Myrtillus* type forests were concentrated in the humus layer and upper few cm of mineral soil while seeds in low herb type forests were scattered throughout the sampled section (12 cm). Granstrom agreed that while his work supports the conclusion that main seed banking species are early successional and species of closed forests typically do not form long lived seeds, there is large variation in seed behaviour not closely linked to successional status. Evidence for this is in the exceptions. Some species favoured by disturbance are not in the seed bank and species not favoured by disturbance dominate the seed bank (*Vaccinium myrtillus*). There are species found in closed forests (albeit more favoured by open conditions) that have seeds in the seed bank.

In northern Sweden 14 species had different responses with burial; depletion rates were not exponential as in agricultural soils (Granstrom 1987). Seeds were buried in nylon envelopes in the F horizon of a coniferous forest for one to five years. Nine species did not germinate, although seeds were viable after five years, especially *Calluna vulgaris* L. Hull. (heather), *Rubus idaeus* and *Rumex acetosella* L. (sheep sorrel). Three species had strong innate germination (*Prunus padus* L. (European bird cherry), *Sorbus aucuparia* L. (European mountain ash), *Trientalis europaea* L. (arctic star flower) and did not germinate in the field for a few years; once dormancy was broken germination in the field was high and seed pools quickly decreased. *Epilobium angustifolium*, *Pinus sylvestris* L. (Scots pine) and *Deschampsia flexuosa* (L.) Trin (wavy hair grass) germinated rapidly in the field at the beginning and quickly depleted from the seed bank

Seeds in Gaspe Peninsula forests in southern Quebec (litter and mineral soil to 10 cm) along an altitudinal gradient of montane, subalpine and alpine sites were concentrated (82 %) in the top 3 cm of soil (Morin and Payette 1988). A total of 35 species were represented in the seed bank, 81 % were present in above ground vegetation; there was a close relationship between the two species pools which is somewhat unusual for such studies. Less than half the species had viable seeds (15 species). Number of seeds and species richness in the seed bank were not linearly correlated with altitude but species composition was related to altitude with a shift from boreal to arctic-alpine types in the seed bank.

Archibold (1989) studied boreal and western montane forests, concluding that seed banks of northern coniferous forests had few viable seeds, dominant species were poorly represented and early successional species were numerous. In Alaska *Picea glauca* (Moench) Voss. (white spruce) regenerated from seeds dispersed onto the site, *Picea mariana* (Mill.) BSP (black spruce) growth was related to unopened cones, *Betula papyrifera* underwent seedling reproduction and *Populus tremuloides* and *Populus balsamifera* L. (balsam poplar) regenerated from root suckers and wind dispersal (Lutz 1956 in Archibold 1989).

In two *Pinus banksiana* and two *Picea glauca* stands southeast of Slave Lake, Alberta, 505 to 2,650 seeds / m^2 were found; 47 to 78 % were in the LFH layer rather than 5 cm of mineral soil below (Fyles 1989). These densities were higher than in other northern coniferous forests but they can be explained by current vegetation composition history, which may be more important than the effect of latitude on seed banks (Johnson 1975). Thirteen species in the seed bank were identified, approximately half of these were in the extant vegetation.

Rydgren and Hestmark (1997) found 34 taxa in a bryophyte and vascular plant propagule bank in boreal forests in Norway, more than twice the number Fyles (1989) found in Alberta forests. Ferns and mosses, not included in Fyles' work, accounted for a large portion. Although similarity between the seed bank and above ground vegetation was described as moderate, the researchers suggested the propagule bank would be valuable for in situ regeneration, depending on degree of disturbance. Propagule bank composition in the litter layer (0 to 5 cm) was more similar to extant vegetation than the peaty mor layer (5 to 10 cm) or bleached layer (10 to 15 cm) and contained more species than lower layers.

More recently, researchers in the Athabasca oil sands reported 3,614 and 9,108 emergents / m^2 in the upper 10 cm of pre-mining peatlands and upland forests, respectively (Mackenzie and Naeth 2010). Total species richness was greater in forest soil (37) than peatland (19), as were number of propagules of grasses, sedges, rushes, forbs, native species, perennial species and annual/biennial species. Almost 90 and 60 % of emergents were from seed in forest soil and peatland, respectively. This is in contrast to Fedkenheuer and Heacock (1979) who found much lower species richness in fresh peat, although depth of sampling was unknown and dilution of the seed bank could have occurred.

The propagule bank of coarse textured forest soils had lower emergent densities (1,189 emergents / m^2 from combined depths) than fine textured soils; species richness was comparable (31 species) (Mackenzie 2012). A large proportion of emergents were from vegetative propagules (71 %). The most abundant group in the propagule bank was woody plants (50 %), followed by forbs (19 %), grasses (14 %), pteridophytes (9 %), sedges (4 %), lily and typha (4 %).

Seed banks in young forests (11 years since cutting) at the southern edge of the boreal forest (at Genesee coal mine in west central Alberta) were more species rich than in the Athabasca oil sands region. In the upper 10 cm of these young forests 42 species (4 graminoids, 35 forbs, 3 shrubs) were identified; 32 were native. Dominant species (*Carex* sp. L. (sedge), *Rubus idaeus*, *Calamagrostis canadensis*, *Taraxacum officinale* Weber (common dandelion), *Veronica peregrina* L. ssp. *xalapensis* (HBK) Pennell, *Galeopsis tetrahit* L.(hemp nettle) and *Epilobium ciliatum* Raf. (fringed willowherb)) were ruderal or early successional (Fair 2011). Depth affected species richness but not density of emergents; the upper depth had more forb and non-native species. Species composition of the seed bank was not similar to above ground vegetation; 19 species from above ground vegetation were missing from the seed bank and 27 species from the seed bank were not present in above ground vegetation.

Hills and Morris (1992) summarized much of the scientific information on boreal forest seed banks. Densities of seeds in the boreal seed bank can be quite high, but viability of these seeds can be quite low. Depth of burial can affect viability; 5 cm was the threshold beyond which viability decreased. Composition of the seed bank was typically skewed towards early and mid successional species rather than late successional species (dominant species in boreal forests).

2.5.1 Post fire seed banks

Numerous studies assessed how the boreal forest seed bank is affected by large disturbances such as fire and logging, and how this relates to the subsequent development of vegetation. The earliest study in the boreal forest by Archibold (1979) found an average viable seed density of 426 plants / m^2 in the seed bank in burned forests of northern Saskatchewan, Canada. This study examined the effect of fire on the seed bank and subsequent regeneration from the seed bank. Germination from seed (87 %) was greater than germination from roots and rhizomes (13 %) in soil to a depth of 10 cm after a fire. Germinant life forms were 39 % trees, and 32, 16 and 13 % *Carex* spp., herbs and shrubs, respectively. Most germination occurred with a moderate burn and least without fire.

In a *Pinus banksiana* ecosystem in eastern Ontario, 64 % of emergents from soil cores (litter and 6 cm of mineral soil) were from seed and 36 % from vegetative propagules (Whittle et al. 1998). Grasses dominated seed emergents (89 %) and shrubs dominated vegetative emergents (75 %). Twenty species were found, 15 from seed, 8 from vegetative propagules and 3 from both, *Maianthemum canadensis* Desf. (lily of the valley), *Vaccinium angustifolium* Aiton (low bush blueberry) and *Carex houghtonii* Torr. (Houghton's sedge). Root systems of vegetatively reproducing species were examined. Herbaceous species, *Linnaea borealis* L. (twin flower), *Carex houghtonii*, *Gaultheria procumbens* L. (eastern teaberry) and *Maianthemum canadense* generally had rhizomes in LFH layers or at the interface with mineral soil. *Lycopodium obscurum* L. (ground pine), *Lycopodium complanatum* L. (ground cedar) and *Pteridium aquilinum* L. (Kuhn) (bracken) tended to have rhizomes in the top 4 to 9 cm of mineral soil. Other species, shrubs, subshrubs and one forb, had rhizomes at depths greater than 25 cm. *Rubus allegheniensis* Porter (Allegheny blackberry) had rhizomes in all layers. Researchers suggested that the results confirmed depth of burial was critical to early post fire dominance for both seed and vegetative propagules.

Using the 85:15 ratio of emergents from seed vs rhizomes and remnant roots found by Archibold (1979) and the 65:35 ratio from Whittle et al. (1998), Lee (2004) surmised differences were related to disturbance intensity, with intense disturbances favouring seed bank regeneration. Seed and propagule bank samples to 10 cm, including litter and mineral soil from unburned, lightly burned and severely burned areas and above ground vegetation monitoring confirmed fire intensity modified the ratio of regeneration from seed vs vegetative banks.

In forests in northern Sweden, Schimmel and Granstrom (1996) found that depth of burn was more important than fire intensity for regeneration of the understory. Small plots (2 m^2) were established in the field and fuel was applied to create fire of different burn depths. Propagule bank samples were collected from moss and lichen (3 to 4 cm), mor (F and H horizons (4 to 5 cm)) and 4 cm layers of underlying mineral soil. Monitoring occurred for five years. *Vaccinium myrtillus*, *Vaccinium vitis-idaea* L. (bog cranberry) and *Deschampsia flexuosa*, which often have rhizomes in the mor layer, returned to or exceeded pre-fire levels two to four years after fires that consumed the moss layer. Bud banks for these species decreased with increased fire depth. Deep burning fires first eliminated *Deschampsia flexuosa* and the deepest fires destroyed *Vaccinium* spp. Seed densities of banking species, often found in the lower mor layer or upper mineral soil, decreased with increasing fire depth. Moderately deep fires encouraged colonization from seed while fires that burnt most of the organic layer negatively affected seed bank species. Effects were visible after five years.

Archibold (1989) reviewed methods that species use in regeneration after fire. Some shrubs, such as *Arctostaphylos uva-ursi* (L.) Spreng. (common bearberry) and *Empetrum nigrum*, originated from buried seed, but most shrubs regenerated vegetatively (Lutz 1965 cited in Archibold 1989). Most herbaceous species invaded burned areas through wind dispersal of seeds. Seed characteristics were important in determining storage time in the seed bank. Only short term storage was noted for *Alnus crispa* (Ait.) Pursch (green alder), *Salix* spp. L. (willow) and *Vaccinium* spp. (Viereck 1973 cited in Archibold 1989), which have thin, soft seed coats providing little protection from fire. Plants with thick, hard seed coats such as *Viburnum* spp. L. (cranberry), *Rosa* spp. L. (rose), *Cornus* spp. L. (dogwood), *Geocaulon* spp. Fern. (bastard toadflax), *Corydalis* spp. Medic. and *Shepherdia* spp. Nutt. (buffaloberry), were persistent, fire dependent residents of the seed bank. Archibold (1989) noted that fire and time since fire played a role in determining which pecies were present in the seed bank through differential burning of upper soil profile layers. Time since fire and seed viability interacted to determine species composition in the seed bank at a given time.

2.5.2 Post logging seed banks

In forests of north western Ontario, Qi and Scarratt (1998) found that harvesting did not affect seed bank density or richness but altered depth distribution of seeds. Post harvest, most seeds were found in LFH, greater than 2 cm below the surface not in the 0 to 2 cm layer; species richness declined with depth. Seed densities were higher than in other studies (9,170 to 9,690 seeds / m^2). Dominant species in litter were *Betula papyrifera*, *Trientalis borealis* Raf. ssp. *latifolia* (Hook.) Hult. (star flower), *Maianthemum canadense*, *Mitella nuda* L. (bishop's cap), *Diervilla lonicera* Mill. (northern bush honeysuckle), *Rubus idaeus*, *Rubus pubescens* Raf. (dewberry) and *Aralia nudicaulis* L. (wild sarsaparilla). Dominant species in upper mineral soil (0 to 6 cm) were *Carex houghtoniana* Torr. *Cornus canadensis* L. (bunch berry), *Geranium bicknelli* Britt. (Bicknell's geranium) and unidentified sedges and grasses. Seeds of conifer species were conspicuous by their absence. A dominant hardwood stand was predicted to develop at the sites.

Caners et al. (2009) investigated the bryophyte diaspore bank in boreal forest at the Ecosystem Management Emulating Natural Disturbance experimental area in north western Alberta. Neither forest type (broadleaf, conifer) nor harvesting intensity (10, 50, 75 and 100 % retention harvesting) affected bryophyte diaspore bank composition. Soil calcium, pH, sodium, charcoal, potassium, LFH depth, silt and spatial proximity were most important. Soil was sampled from LFH and mineral soil (to 5 cm) separately. A total of 56 species germinated; most were perennial (37 %) or colonist species (33 %). Other life history strategies were fugitive (1.9 %) and short (14 %) and long lived (15 %) shuttle strategies.

2.5.3 Post removal experiments seed bank

Removal experiments have been used to assess the role of seed banks after disturbance. Jonsson (1993) removed vegetation or vegetation and humus in high elevation *Picea abies* forest in north western Sweden, finding rich bryophyte diaspore banks (31 taxa germinated) and propagule sources for regeneration. Correlations were significant between species richness of the diaspore bank and regenerating vegetation; which were more similar than the diaspore bank and undisturbed vegetation. Before disturbance species number was higher in mineral soil (to 3 cm) than humus; but opposite four years later. The study does not support previous work, but reaffirms dominance of early successional species in the seed bank, and absence of abundant forest floor species.

Hautala et al. (2001) used small plots with no removal; removal of ground layer (bryophytes and lichens); removal of understory layer; removal of moss and understory layers; removal of moss, understory and humus layers; and sowing

Vaccinium myrtillus and *Vaccinium vitis-idaea* in *Hylocomium-Myrtillus* boreal forests in northern Finland. Vegetative reproduction was most prevalent with moss and understory removal, a moderate disturbance. *Vaccimium vitis-idaea* recovered faster than *V. myrtillus* through vegetative growth. Seedling density was highest with sowing and removal of moss, understory and humus, indicating sexual reproduction was enhanced with high mechanical disturbance. In another study disturbance type and growth form played a role (Hautala et al. 2008). Complete recovery of understory cover (mainly clonal dwarf shrubs) occurred after four years in all but the most severe treatments where humus was removed; bryophyte cover did not recover in any treatment from which it was removed. Understory plants developed from preserved underground parts, mostly removed with humus. Species richness did reach control levels in the most severe treatment after four years. Bryophytes and graminoids (most prevalent) developed with humus removal, indicating preference for exposed mineral soil.

In south eastern Norway Rydgren et al. (1998, 2004) removed vegetation; vegetation and litter; vegetation, litter and mor soil layer; and vegetation, litter, mor soil layer and bleached soil layer. There were two permutations of the latter treatment, one with the removal plot adjacent to intact vegetation and one with it in the centre of the treatment. After three years species richness of vascular plants recovered (reached or exceeded pre-treatment level) on all treatments, but richness of bryophytes and lichens had not (Rydgren et al. 1998). Species that resprout from rhizomes after disturbance responded differently to disturbance than species that rely on a persistent seed bank or species that disperse from adjacent areas. After seven years a gradient in pioneer species became apparent; number of pioneer species increased for the first three years and then subsequently declined and/or levelled off (Rydgren et al. 2004). Researchers noted a second gradient; between the second and third year species composition shifted to be more similar to composition of the propagule bank.

2.6 Use of Propagule Banks In Forest Reclamation

2.6.1 Non-boreal forest studies

Some of the earliest research on use of forest litter layers and topsoil as a seed source for reclamation took place at Alcoa bauxite mines on the Darling Plateau in Western Australia, in the *Eucalyptus marginata* Donn ex Sm (jarrah) forest. Bauxite ore is typically 4 m below the surface (Koch and Ward 1994). Topsoil and overburden layers, salvaged prior to mining, vary from a few cm to 1 m, with an average depth of 40 cm. The upper 5 cm are enriched in organic matter, seeds and nutrients, and are referred to as topsoil; the remainder is overburden.

Most seeds (93 %) in jarrah forest topsoil were from the top 2 cm, based on 10 cm samples of undisturbed forest after clearing vegetation for mining (Tacey and Glossop 1980). Koch et al. (1996) found 9 % in forest litter, 26 % at 0 to 2 cm, 35 % at 2 to 5 cm and 28 % at 5 to 10 cm. Ward et al. (1997) found 10 % in litter, 51 % in 0 to 2 cm depth interval and 39 % in 2 to 5 cm depth interval.

While seed densities in jarrah forests seem quite promising; 377 to 876 seeds / m^2 (Vlahos and Bell 1986), Bell et al. (1990) concluded that seed reserves in topsoil were insufficient to create flora of native jarrah forest and would need supplementation with germinable seed and nursery stock. Annuals, biennials and subshrubs are well represented jarrah forest seed banks while perennial trees are not (Vlahos and Bell 1986 cited in Bell et al. 1990, Ward 1997); shrubs were abundant in some studies (Ward 1997) and lacking in others (Vlahos and Bell 1986 cited in Bell et al. 1990). There are issues with production and viability of seeds in the jarrah forest (Bell et al. 1990). Legumes were the only species for which viable seeds can be obtained (Glossop 1980 cited in Bell et al. 1990); non-legume seeds were generally not viable (Moore 1973 cited in Bell 1990). Jarrah forest re-sprouter species tend to produce few seeds which are often not viable, in contrast to re-seeder species which produce large amounts of viable seed. Re-sprouter species account for 75 % of understory in undisturbed forest.

Most work in Western Australia focused on refining the use topsoil as a seed bank in reclamation. Tacey and Glossop (1980) found double stripping (direct placing upper 5 cm on 40 cm of stockpiled overburden) was the best way to reclaim jarrah forest to approach diversity of the original forest. Double stripping was compared to direct whole return (placing the entire 40 cm of salvaged topsoil and overburden profile) and stockpiling (salvaging to 40 cm and storing for two years). Approximately 0.1 % of seeds from the upper 5 cm of undisturbed forest soil germinated and emerged on double stripping treatments after 18 months, raising concerns about the potentially significant losses of seeds to burial. Three years later results were similar, with some increases in similarity indices between vegetation on reclaimed and natural forests (Nichols and Michaelsen 1986). While no treatments could be described as very similar to undisturbed forests, the double stripped treatment continued to be the most similar, especially in height, structure and cover of individual understory species.

Concerns about seeds being buried too deeply during soil placement were addressed by Grant et al. (1996) using 12 species with different life forms (herb, geophyte, climber, shrub, tree, grass) and seed characteristics buried at 0, 1, 2, 5, 10, 15 cm. Most species had highest germination and emergence when buried 0 to 2 cm below the surface. Germination was dramatically reduced with seed burial deeper than 5 cm and thus a 5 cm soil placement depth was suggested.

Koch and Ward (1994) studied impacts of fertilizer, seeding and pre-mining vegetation (prior to clearing) on revegetation at nine sites reclaimed using double strip, direct return or stockpile methods. Vegetation was assessed nine months after treatment. Seeding with a legume and shrub mix resulted in the highest plant density, cover and species richness; seeding with smaller, less aggressive species or no seeding, led to a plant community more closely approximating undisturbed forest (similarities 22 to 49 %). Overall, 48 jarrah forest species were missing from reclaimed sites and high seed producing, r-type species dominated. Topsoil was the source for 129 (77 %) non-weed species on the plots; broadcast seed was the major source for 39 (23 %) non-weed species.

To understand low efficiency of seed transfer from salvaged topsoil to reclaimed sites (0.1 % from Tacey and Glossop 1980), a detailed accounting of seed stores at stages of soil handling at three sites was undertaken (Koch et al. 1996). Seed store was reduced to 74 % of original seed bank density after clearing and burning, further reduced to 31 % in fresh stockpiles and 13 % after ten months in a stockpile followed by spreading. Direct return soil had 31 % of original density after spreading. Ripping increased seed density at two sites (53 % with direct return, 21 % with stockpiling). Seed losses were substantial between each step, however, shorter delays between initial soil removal from pre-disturbance sites and post-disturbance spreading helped minimize seed loss. After reclamation, seeds were evenly distributed over the 20 cm sampling depth, and since losses were based on this depth, the number of seeds that could germinate was much lower considering that the maximum depth from which seeds can actually germinate is 5 cm. Hard seeded species were more likely to survive salvage and placement than small seeded species lacking hard seed shells or seed coats.

A large number of species (72 % on reclaimed site) germinated only from applied topsoil, not seed; fresh topsoil provided more species than stockpiled (Ward et al. 1996). Timing of soil ripping and scarification had a greater effect on topsoil applied than seeded species. To optimize establishment of seeded species and those from applied topsoil, ripping, scarification and sowing should occur by April (Australia fall). Optimal timing of salvaging topsoil prior to mining was December (Australia summer), which coincided with optimal timing of seed bed preparation (Ward et al. 1997). These optimal times were based on seed density enumeration and germination studies on samples (litter and mineral soil from 0 to 5 cm) collected in four seasons from six plots at three bauxite mines in Western Australia. When seeds were heated there were significant positive effects on six species and negative effects on 13 species. Smoke water had a positive effect on one species. Samples were stored for different times after collection which may have affected results. In another study, treating seeds to be broadcast with smoke or smoke water doubled success and treating field sites with applied topsoil increased number of emerging seedlings by 50 % (Bell 2001).

Koch (2007) described refinements to techniques employed at Australian bauxite mines to maximize topsoil as a seed source. To reduce seed burial to depths too great for germination, seeds were concentrated by sieving with a 5 mm screen, through which 99 % of seeds in topsoil passed, producing a smaller volume of seed rich material. Koch and Hobbs (2007) reviewed bauxite mine reclamation in Western Australia finding applying topsoil, fertilizer and seeding nitrogen fixing legumes created sites with plant growth, litter accumulation, nutrients and decomposition rates similar to undisturbed forests. As of 1995, restored areas had the targeted 80 % species richness desired by mining companies (Koch 2007). Bell et al. (1990) found re-seeder species (regenerate through seeds) and ephemeral species were over represented in reclaimed relative to undisturbed areas, and there was a scarcity of re-sprouter species (regenerate by sprouting from vegetative parts) (Koch 2007). Recalcitrant species have been planted when topsoil seed stores and seed collections do not provide all target species.

Reclamation following sand extraction in the *Banksia* ecosystem in Western Australia uses replaced topsoil as a seed source (Rokich et al. 2000). Minimizing stockpiling and burial depths maximized seed germination of a woody evergreen, *Banksia*, as did stripping and spreading in fall. Most species did not emerge from depths greater than 2 cm; 1 cm burial was optimal. Salvage depth had a greater impact on seedling recruitment than application depth. Salvaging at a 10 cm depth was more favourable for seedling recruitment. Ripping had no impact on seed germination and could continue to be used to alleviate compaction.

A micro plot experiment with forest topsoil collected to 10 cm (without litter) was conducted in the Appalachian Mountains in Tennessee (Farmer 1982). Two mine soils and nursery soil (control) were used as substrates, and forest topsoil was obtained from three local forested sites. Based on monitoring first year growth, use of forest top soil, even without litter, provided a diverse plant community that quickly covered areas reclaimed after coal mining. Aggressive annual and perennial pioneer species, low growing species and a tree species dominated.

A similar experiment was conducted in the Appalachian Mountains on plots with fertilizer and straw mulch (Wade 1989). The seed bank from forest topsoil (no litter) was a good source of propagules for revegetation. In the first growing season, 5 tree species, 7 shrubs and woody vine species, 14 grasses and 53 forbs emerged. In sterilized and unsterilized forest topsoil a seed mix of mainly grass species reduced total and native species biomass and species diversity. Little difference in canopy cover was observed between treatments.

In Kentucky applied forest topsoil (upper 15 cm) and a reclamation seed mix were studied (Wade and Thompson 1990). Treatments were 1 cm topsoil plus mulch, 1 cm topsoil lightly rototilled into soil plus mulch, 2 cm topsoil plus mulch, 1 cm topsoil, 1 cm topsoil in two strips 4 cm deep plus mulch, 1 cm topsoil plus a reclamation seed mix plus mulch, reclamation seed mix plus mulch, and mulch. Topsoil significantly increased native species richness in two growing seasons; cover of native species was low (maximum 7 % on topsoil) with no treatment differences. Most cover was provided by seeded species or seeds in mulch.

Use of forest topsoil as a seed source in reclamation in Kentucky was studied at a larger scale (Hall et al. 2010). Soil was salvaged to 50 cm then stockpiled. Small samples from stockpiles were removed one week later and applied to 2 x 5 m plots at a depth of 10 to 20 cm. Prior to salvaging vegetation was assessed and litter and soil samples to 15 cm were collected for germination assays in the greenhouse. Litter samples had more seeds of some species than soil samples. Forest topsoil and litter were considered important seed sources for revegetation of disturbed areas but may be lacking in some dominant species from late succession stages, particularly trees. Fewer species germinated in outdoor topsoil plots (69) than in the greenhouse (105); many were herbs, grasses, sedges and rushes. Trees, shrubs and woody vines dominated pre-disturbance forest. Half (39) the species germinating in topsoil were present in pre-disturbed forest, with more non-native species in topsoil than in pre-disturbance forest.

Construction at the Channel Tunnel terminal in Kent necessitated relocation of ancient woodland soil to a receptor site a couple hundred meters away (Helliwell et al. 1996). The donor site was stripped to 20 cm and soil transferred to a receptor site with topsoil removed. The seed bank in woodland soil was successfully transplanted from one site to another. Constraints were expected from competition from ruderal species and receptor site suitability. A total of 176 species were found at the receptor site six years after transfer; 83 of which were found in the original woodland. The other 93 species were mainly ruderals.

Salvaged upland surface soil material was effective in revegetating tundra at high elevations in south eastern British Columbia (Smyth 1997). Applying 5 cm of salvaged LFH, Ah and Bm materials and seeding 42 native species worked best for land reclamation with fastest establishment and greatest cover. After five years cover on applied topsoil with seeding was 82 %, relative to 25 % on topsoil only, 65 % on seeding only (spoil soil material) and 8 % on spoil, no seeding control. A total of 54 species established, 11 grasses, 4 sedges, 38 forbs and 1 shrub. Pioneer grasses dominated initially, although forbs became more prominent with time. Over time, species richness and diversity began to converge to that of adjacent areas through transportation of seeds to the disturbed area.

2.6.2 Boreal forest studies

Only a small number of studies exist on seed banks use in reclamation in boreal forest. A study at Genesee coal mine in west central Alberta supports using upland surface soil or LFH mineral soil mix as it has potential to establish species rich native plant communities (Fair 2011). After one year an early successional plant community with 73 species (4 graminoid, 59 forb, 10 shrub) established; 49 were native. Dominant species were *Galeopsis tetrahit*, *Symphoricarpos albus* (L.) Blake. (snowberry), *Vicia americana* Muhl. (wild vetch), *Calamagrostis canadensis* and *Rubus idaeus*. Of 73 species 41 were from the donor site. There were 21 species lost at the reclamation site, most notably *Cornus canadensis*, and 32 species gained of which 18 were native. A 15 cm salvage and application produced greater cover and species richness, but was not superior to 40 cm salvage and application in species composition; the researcher suggests either could be used. The 11 plant species missing from the 40 cm application depth were a mixture of annual, non-native species and perennial, native species.

A three year study was conducted in southeastern Norway on forest topsoil, the upper 30 cm of soil, in roadside revegetation (Skrindo and Halvorsen 2008). Topsoil and subsoil were stored for one year in separate stockpiles then 10 cm applied. Species richness and organic matter were similar between subsoil and topsoil amended plots but species composition differed. Topsoil had herbaceous and woody species typical of forest edges and interiors while subsoil often had weedy species. Forest topsoil resulted in a higher frequency of trees and shrubs.

2.7 Reclamation Practices In The Athabasca Oil Sands

Reclamation of oil sands mines is required by law in Alberta through the Environmental Protection and Enhancement Act (Government of Alberta 2000) and associated Conservation and Reclamation Regulation (Government of Alberta 1993). The goal of reclamation is to return land to equivalent capability defined as “the ability of the land to support various land uses after conservation and reclamation is similar to the ability that existed prior to an activity being conducted on the land but that the individual land uses will not necessarily be identical” (Government of Alberta 1993). Specific reclamation practices must be followed and operating conditions for the mine and associated facilities are defined in each company’s approval which must be updated periodically as specified in the approval. Recent approvals state that land should be reclaimed such that it is capable of supporting self-sustaining, locally common boreal forest ecosystems, regardless of end land use (Alberta Environment 2007a, 2007b, 2007c, 2007d, 2009, 2011). Commercial forests and non-commercial forests are main categories of end land uses. End land uses for non-commercial forests include wildlife habitat, traditional use or recreation (Alberta Environment 2010).

After planning, the first step in reclamation and mining is clearing timber and salvaging soil and overburden. Timber is sold or used in reclamation as woody debris. Oil sands overburden is of variable quality, some saline sodic (Clearwater material), some non-reactive. Oil sands without an oil concentration to make extraction economically feasible are lean oil sands (Macyk and Drozdowski 2008) and are used like overburden in reclamation. Secondary material from suitable upland soil or surficial geologic material salvaged to a depth not considered suitable for plants (Yarmuch 2003) is generally fine textured, non-saline and non-sodic. These materials are placed in large mine dumps and become a feature on the reclaimed landscape which must be reclaimed. Overstripping peat deposits creates peat mineral soil mix, which has been the dominant cover soil for reclamation to date. A 60:40 or 70:30 ratio of peat material to mineral material has been most suitable (Macyk and Drozdowski 2008). LFH mineral soil mix is now used and is obtained by overstripping LFH in upland forest soils to 15 to 30 cm depending on ecosite (Alberta Environment 2007a, 2007b, 2007c, 2007d, 2009, 2011). Once salvaged, materials are stockpiled or direct placed in reclamation areas. Subsoil is salvaged and stockpiled separately.

The other main feature on the reclaimed landscape is tailings ponds which are located in formerly mined pits. Tailings are materials left after bitumen has been extracted. They are generally liquid or semi-liquid but there are some solid streams of tailings (tailings sand). Solidification of liquid tailings has been and continues to be one of the greatest reclamation challenges. However, tailings reclamation is not the focus on this study and will not be discussed in detail. Dykes that contain tailings ponds can be reclaimed similar to overburden dumps.

Areas to be reclaimed are covered with soil materials prescribed by operating approvals. Generally 20 to 50 cm of cover soil (or cover soil over subsoil) is required, and must be separated from poor quality material, such as lean oil sand or saline sodic overburden, by 1 m of clean material. These depths provide sufficient seed bed and rooting zone for boreal plants. Research to confirm optimum depths continues, particularly with coarse textured materials. Reclaimed areas are then fertilized and planted with a cover crop (generally barley, recently native grasses). In the same season native trees and shrubs are planted to densities recommended in Guidelines for Reclamation to Forest Vegetation in the Athabasca Oil Sands Region, Second Edition (Alberta Environment 2010). Trees and shrubs, grown from locally collected seed, are acquired from local nurseries. Longer term reclamation activities consist mainly of weed control and monitoring. Macyk and Drozdowski (2008) provide a comprehensive review of operational reclamation practices at oil sands mines and Alberta Environment and Water (2012) describe best management practices for handling reclamation materials.

Oil sands reclamation must account for landscape scale issues such as water flow and drainage among landforms. This can be complex at lease boundaries as different operators must work together to integrate plans. Integrating wetlands, specifically peatlands, into the final reclamation landscape will play an important part in connecting reclaimed upland areas.

2.8 LFH Mineral Soil Mix Propagules For Oil Sands Reclamation

2.8.1 Propagule bank effects

The earliest study on the seed bank of reclamation materials in the oil sands examined the composition of fresh and stockpiled peat (Fedkenheuer and Heacock 1979). Plots were established on a tailings sand base; 15 cm of fresh and stockpiled (1.0 to 1.5 years old) material was placed over 10 cm of mineral fines (clay) and rotovated to 30 cm. After two growing seasons stored peat had greater species richness (8) than fresh peat (5); fresh peat had more emergents. Species composition was similar on both treatments with *Corydalis aurea* Willd. (golden corydalis), *Epilobium angustifolium*, *Vicia americana*, *Equisetum* spp. L. (horsetail) and *Graminaea* spp. The low species numbers questioned the value of the seed bank as a source of native species propagules in peat amendments.

Anyia (2005) studied changes in seed density and species richness related to reclamation soil (peat mineral soil mix) salvaging prior to mining at Shell Albian Sands. Emergent densities from natural soils were 0 to 175 ± 83 plants / m^2. This was higher than the densities for reclamation soil of unspecified origin or depth under the same treatments (0 to 133 ± 70 plants / m^2). Low species richness (18) in both soil types and low emergent densities led to the conclusion that seeds alone will not be sufficient for reclamation and vegetative propagules and ingress via wind and animal dispersal will be very important for revegetation.

Mackenzie and Naeth (2010) collected propagule bank samples immediately after placing fine textured forest soil and peat material on an overburden dump. Density of emergents from the propagule bank was lower than in undisturbed soils in the area (95 % losses in LFH mineral soil mix, 91 and 77 % losses in 10 and 20 cm peat mineral soil mix, respectively). Application thickness played a larger role in determining propagule density than propagule source. A 99 % loss of vegetative parts was estimated. Decreased emerging propagules were attributed to dilution effects and loss of viability during stockpiling. LFH mineral soil mix (10 and 20 cm) had 29 species compared to 16 species in peat mineral soil mix (10 and 20 cm applications). LFH mineral soil propagule banks were more similar to vegetation of the donor site than that of the peat mineral soil mix.

In a similar study, after placing coarse textured forest soil in reclamation areas, emergent densities from propagule bank samples showed greater than 90 % loss of propagules. Unlike in the natural setting, most emergent were from seed rather than vegetative propagules (Mackenzie 2012). Species richness was 18 species.

Mackenzie (2012) studied viability loss of seeds and vegetative propagules in stockpiles. Four sets of large and small stockpiles were established at oil sands mines. Three sets were constructed with coarse textured material, the fourth with fine textured material. One coarse textured set was established in winter, the others in fall. Large stockpiles could accommodate operational size equipment; small stockpiles were windrow size. Seeds of 10 shrub species and one tree and root cuttings of three shrub species were buried in mesh bags at various depths in stockpiles. In large stockpiles, most seeds and roots buried deeper than 1 m lost viability after eight months; the same occurred in small stockpiles after 12 months. Loss of viability occurred more slowly in winter constructed stockpiles; after 12 months results were the same.

Other work on germination cues in boreal species and methods to improve germination operationally has been undertaken. Anyia (2005) studied the effect of water, light and temperature on germination. Water was the most important environmental variable affecting germination. In natural soils germination was higher in dry soil with summer temperatures while in reclaimed soils germination was higher with saturated soils and spring temperatures. Plant derived smoke water was used at bauxite mines in Australia (Roche et al. 1997, Rokich et al. 2002) to enhance germination. Both Anyia (2005) and Mackenzie (2010) found positive results for boreal forest species, although results were species specific and varied with stratification treatments, soil water and temperature.

2.8.2 Revegetation effects

Syncrude Canada Ltd. initiated the first LFH mineral soil mix study. LFH and underlying mineral soil were salvaged to 7.8 cm and directly placed on a tailings dyke in August 1998 (Lanoue and Qualizza 2000, Navus Environmental Inc. 2009). Some material was stockpiled and placed in January 1999 (Lanoue and Qualizza modified by Pollard 2001). Treatments were winter and summer placement of LFH mineral soil mix over peat mineral soil mix over secondary material, winter placement of LFH mineral soil mix over secondary material, peat mineral soil mix over secondary, (Lanoue and Qualizza 2000) and natural forest (in 2001) (Pollard and Leskiw 2002). Plots were fertilized and seeded with *Hordeum vulgare* L. (common barley) prior to LFH mineral soil mix placement (Lanoue and Qualizza 2000). Lack of replication precluded statistical analyses.

In 2008, after 10 years, LFH mineral soil mix placed on peat mineral soil mix or secondary increased native species regeneration relative to controls (Navus Environmental Inc. 2009). All LFH mineral soil mix treatments had a greater number and abundance of native and woody species. Although not statically compared, LFH mineral soil mix treatments were more similar to undisturbed forests (Navus Environmental Inc. 2009). While early reports concluded that summer placement was superior to winter placement (Pollard and Leskiw 2002, Brown et al. 2003, Mapfumo 2003), the effect of winter and summer placement was variable through time and there was no conclusive evidence supporting one or the other (Navus Environmental Inc. 2009). Canopy cover and species richness were numerically higher on LFH mineral soil mix over peat mineral soil mix than secondary; woody stem density and diversity were similar for both.

Suncor Energy Inc. (Suncor) began a similar experiment on Steepbank North Dump in 2000 (AMEC 2007). An LFH mineral soil mix consisting of LFH layers and a sandy Ae horizon was stripped to 20 cm from a fine textured, mesic (d) ecosite with patches of submesic (b) ecosite, as defined by Beckingham and Archibald (1996). The site was cleared three years prior to soil salvage. Four treatments were established including 20 cm of LFH mineral soil mix, 20 cm mix of LFH mineral soil mix (30 to 40 % by volume) and peat mineral soil mix (60 to 70 % by volume), 5 cm cap of LFH mineral soil mix over 15 cm of peat mineral soil mix and a control of 20 cm of peat mineral soil mix. Treatments were replicated twice on a west facing 4:1 slope of a lean oil sand overburden dump. *Hordeum vulgare* was seeded and *Populus tremuloides* and *Picea glauca* were planted; plots were fertilized from 2000 to 2003.

Forbs (58 to 70 % cover) dominated treatments after five years, particularly non-native species such as *Sonchus arvensis* L. (sow thistle), *Crepis tectorum* L. (hawks beard) and native species such as *Erigeron philadelphicus* L. (fleabane) and *Achillea millefolium* L. (common yarrow) (AMEC 2007). Grasses were next abundant followed by shrubs then trees. Few significant differences in growth form occurred annually, with the exception of greater grass cover on the 20 cm LFH mineral soil mix and the mixture of LFH mineral soil mix combined with peat mineral soil mix, which may be of concern for tree establishment (AMEC and Golder Associates 2010). Controls had less grass cover and greater tree cover than LFH mineral soil mix combined with peat mineral soil mix. Cover soil did not affect height or survival of planted trees. Two samplings in 2005, one more intense, yielded different results. Total, litter, vegetation, forb and grass cover were significantly highest for LFH mineral soil mix with peat mineral soil mix. This treatment had significantly higher shrub cover than the control.

Mackenzie and Naeth (2010), at Syncrude base mine on an overburden dump found that 10 and 20 cm applications of LFH mineral soil mix from mesic (d) ecosites had greater species richness (49 and 47 species, respectively) and plant abundance (20 and 36 %, respectively) than peat mineral soil mix (24 and 25 species, 6 and 5 %, respectively) after two years. Species emerging on LFH mineral soil mix were more mesic, upland suited than those emerging from peat mineral soil mix. LFH mineral soil mix had higher woody plant densities, 20,000 and 69,000 stems / ha on 10 and 20 cm applications, respectively, in the third year (unpublished data from Mackenzie and Naeth 2008, 2010 cited in Alberta

Environment 2010). Dominant shrubs were *Rubus idaeus*, *Rosa acicularis* Lindl. (prickly rose) and *Ribes* spp. L. (currant). After year two both LFH mineral soil mix treatments had higher total (20 to 37 %), forb (17 to 29 %), grass (2 to 3 %), native (15 to 24 %), perennial (17 to 31 %) and annual/biennial (3 to 5 %) canopy cover than peat mineral soil mix treatments (5 to 6 %, 3 to 4 %, < 1 %, 4 %, 3 to 4 % and 2 % canopy cover, respectively). The 20 cm LFH mineral soil mix had greater cover of non-native species than the 10 cm LFH mineral soil mix and both peat mineral soil mix treatments (with similar non-native species cover).

Mackenzie and Naeth (2008 unpublished) investigated the effect of patch size and slope position on initial plant establishment on a similar overburden dump. Stripping was shallower (2 to 5 cm below LFH) rather than 20 cm as in previous work. The same three dominant shrub taxa were found but with much higher stem densities than their previous study (unpublished data from Mackenzie and Naeth 2008, 2010 cited in Alberta Environment 2010). After the third growing season densities were 77,000 to 100,000 stems / ha, with larger values attained with larger patches and on lower slope positions. There were some issues with flooding of research plots which proved disadvantageous for woody plant growth.

Brown and Naeth (Brown 2010, Brown and Naeth 2012) studied a 20 cm LFH mineral soil mix placed over a 30 cm mix of B and C horizon material and a 30 cm peat mineral soil mix on an overburden dump at Suncor. LFH mineral soil mix had greater species richness (34 vs 25 in the second growing season) and canopy cover (61 vs 32 % in the second growing season) in the first two growing seasons. In the first growing season, canopy cover of native and non-native species was higher on LFH mineral soil mix (6 and 4 %, respectively) than on peat mineral soil mix (both 1 %). By the second growing season, non-native species cover was higher on peat mineral soil mix (15 %) than on LFH mineral soil mix (10 %). In the first two years LFH mineral soil mix had higher cover of forbs (42 vs 27 %), grasses (9 vs 2 %), sedges (6 vs 1 %), woody species (4 vs 2 %), perennial (40 vs 15 %) and annual or biennial (22 vs 17 %) species.

At Syncrude Aurora mine on sand and peat-sand (50:50 mix) substrates, LFH mineral soil mix was salvaged from coarse textured, submesic to xeric ecosites at 10 and 25 cm and was placed at 10 and 20 cm (Mackenzie 2012). Controls with no LFH mineral soil mix were established on peat-sand substrate. After three years LFH mineral soil mix had greater species richness, evenness, diversity, shrub density and canopy cover for most plant groups than peat mineral soil mix. Tree density was significantly greater on shallow salvage and deep placement than peat mineral soil mix. Among LFH mineral soil mix treatments, plant density, cover and diversity were similar on both salvage depths although deeper salvage resulted in greater species richness and shallow salvage resulted in greater tree densities. Thicker application led to increased plant cover. Application depths were more apparent on sand than peat-sand.

2.9 LFH Mineral Soil Mix As A Cover Soil In Oil Sands Reclamation

LFH mineral soil mix provides plant propagules for reclamation, acts as a growth medium for plants and is considered a cover soil in regulatory approvals, with several clauses designating its use (Alberta Environment 2007a, 2007b, 2007c, 2007d, 2009, 2011). Physical and chemical properties of LFH mineral soil mix are more suitable for plants than overburden, secondary material, tailings sand or other tailings streams. Studies suggest it is equivalent or a better reclamation cover than peat mineral soil mix (MacMillan et al. 2006, Mackenzie 2006, Mackenzie and Naeth 2010, Brown 2010, Brown and Naeth 2012, Hahn 2012, Beasse 2012, Mackenzie and Quideau 2012, Mackenzie 2012).

An important aspect of LFH mineral soil mix as a cover soil is that it contains microorganisms of undisturbed forest which contribute to reclamation. Microbial community composition of LFH mineral soil mix was more similar to that of natural forests than peat mineral soil mix (Hahn 2012).

Naeth et al. 2013 provide a comprehensive review of differences between LFH mineral soil mix and peat mineral soil mix in terms of chemical, physical and biological properties. Whether initial LFH mineral soil mix benefits are maintained long term or whether sites reclaimed with peat mineral soil mix eventually develop similar vegetation communities has not been addressed to date.

3. RESEARCH OBJECTIVES AND THESIS ORGANIZATION

The main objective of this research was to examine early ecosystem genesis and key processes associated with it in areas disturbed by large scale oil sands mining. Trajectories that plant communities follow after similar or different starting points and the main drivers (functions and processes) affecting these trajectories were studied.

Chapter II compares a native propagule source (LFH mineral soil mix) to traditional reclamation prescriptions (peat mineral soil mix) in the Athabasca oil sands to determine if differences in vegetation communities on different cover soils persist beyond two or three years. Specific objectives were as follows.

- Compare vegetation on LFH mineral soil mix and peat mineral soil mix 4 to 13 years after reclamation.
- Examine effects of LFH mineral soil mix and peat mineral soil mix application depth on vegetation 4 to 13 years after reclamation.
- Determine whether the effects of LFH mineral soil mix and peat mineral soil mix on vegetation communities are consistent at four different sites.

Chapter III investigates patterns of vegetated areas and bare ground on LFH mineral soil mix and peat mineral soil mix. Specific objectives are as follows.

- Compare vegetation characteristics and soil properties of heavily vegetated and bare areas on LFH mineral soil mix and peat mineral soil mix.
- Determine if different soil – vegetation relationships exist on bare and heavily vegetated areas and if this is affected by cover soil type.
- Compare initial soil properties at reclamation to current soil properties of bare and vegetated areas on LFH mineral soil mix and peat mineral soil mix.

Chapter IV provides a summary of key conclusions and applications to reclamation practices and discusses study limitations and future research.

Chapters in this thesis are meant to stand alone. As a result there may be some duplication of figures, tables and site description sections.

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Figure 1.1. Oil sands deposits and mineable area in north eastern Alberta, Canada (Government of Alberta 2013c).

CHAPTER II. PLANT COMMUNITY DEVELOPMENT ON LFH AND PEAT COVER SOILS IN THE ATHABASCA OIL SANDS REGION

1. INTRODUCTION

Oil sands mining has disturbed 715 km^2 (71,497 ha) of land to date, 0.16 % of Alberta boreal forest (Government of Alberta 2013a). Of this, 104 ha have been certified reclaimed and 4,835 ha permanently reclaimed with the expectation that all of the land disturbed will be reclaimed at the end of mining. This represents a considerable challenge as many materials must be managed and integrated into a final landscape design that can function naturally without human intervention.

One facet of the challenge is upland or terrestrial reclamation, which has changed dramatically since it began in the 1970s. Use of peat mineral soil mix as a cover soil has persisted as it is the most widely available material for this purpose. In 1999 upland surface soil (LFH layers and underlying A horizon of upland forests) was recognized as a potential cover with the added benefit of containing native plant propagules that are not present in other cover soil options and are difficult to source commercially (Lanoue and Qualizza 2000).

Undisturbed, fine textured, upland forest soils in the oil sands region are a rich source of plant propagules with over 9,100 emergents / m^2 relative to 3,600 emergents / m^2 from peat land soils (Mackenzie and Naeth 2010). In both propagule banks, 92 % of emergents were native species. Through salvage, stockpiling and placement 77 to 95 % of propagules were lost, likely from dilution and loss of viability (Mackenzie 2012a). Species richness declined from 37 species in upland surface soil to 29 species in placed LFH mineral soil mix, and from 19 species in peat land soil to 16 in placed peat mineral soil mix. Most emergents (94 to 97 %) from LFH mineral soil mix and peat mineral soil mix directly after placement were native species. After two years at two sites, LFH mineral soil mix had higher plant species richness and abundance relative to peat mineral soil mix (Mackenzie and Naeth 2010, Brown and Naeth 2014). Total, forb, woody, grass, native and non-native cover were higher with 20 cm rather than 10 cm applications of LFH mineral soil mix (Mackenzie 2006, Mackenzie and Naeth 2010). After three years at a coarse textured research site LFH mineral soil mix had greater species richness, evenness, diversity, shrub density and canopy cover for most plant groups than peat mineral soil mix (Mackenzie 2012a). There were significant salvage depth (10 and 25 cm) and application depth (10 and 20 cm) effects on vegetation developing on LFH mineral soil mix. Two longer term studies found that positive effects of LFH mineral soil mix on vegetation community development were maintained for up to 10 years (AMEC 2007, Navus Environmental Inc. 2009) but this has not been fully validated on well replicated, large scale research sites.

2. RESEARCH OBJECTIVES

The main research objective was to examine trajectories plant communities follow after starting points with two different cover soils. Use of a native propagule source (LFH mineral soil mix) was compared to a traditional reclamation prescription (peat mineral soil mix) for the Athabasca oil sands to determine if differences in vegetation communities persist beyond the first few years. Specific objectives were as follows.

- Compare vegetation on LFH mineral soil mix and peat mineral soil mix 4 to 13 years after reclamation.
- Examine effects of LFH mineral soil mix and peat mineral soil mix application depth on vegetation 4 to 13 years after reclamation.
- Determine whether the effects of LFH mineral soil mix and peat mineral soil mix on vegetation communities are consistent at four different sites.

3. MATERIALS AND METHODS

3.1 Study Area

Research sites were located on Syncrude Canada Ltd. (Syncrude) and Suncor Energy Inc. (Suncor) mine leases 25 to 75 km north of Fort McMurray, Alberta, in the central mixedwood natural subregion of the boreal forest natural region (Natural Regions Committee 2006). Short, warm summers and long, cold, winters are typical. Mean annual temperature is 0.7 °C with average daily maximum 23.2 °C in July and average daily minimum -24 °C in January (Environment Canada 2013). Mean annual precipitation is 455.5 mm; 342.2 mm as rain and 155.8 cm as snow. Average frost free days are 97 (Natural Regions Committee 2006). Mean wind speed is 9.5 km / h; most frequently from the east except from the southwest in July and August (Environment Canada 2013).

Topography of the Fort McMurray area is variable and composed of uplands and lowlands with distinct soil types. Upland area soils are mainly Gray Luvisols with fine textured glaciofluvial or medium to fine textured till parent materials, although Eutric and Dystric Brunisols have developed on drier sandy sites (Yarmuch 2003). Organic and peaty Gleysolic soils dominate low lying areas.

Mixedwood forests with varying proportions of *Populus tremuloides* Michx. (trembling aspen), *Populus balsamifera* L. (balsam poplar) and *Picea glauca* Moench (Voss) (white spruce) are the main upland vegetation types (Natural Regions Committee 2006), with some inclusions of *Abies balsamea* (L.) Mill (balsam fir) and *Betula papyrifera* Marsh. (paper birch). *Pinus banksiana* Lamb. (jack pine) forests occur in drier areas. Wetland vegetation typically consists of *Picea mariana* (Mill.) BSP. (black spruce), *Larix laricina* (Du Roi) K. Koch (tamarack) and *Salix* spp. L. (willow).

Upland plant communities are classified into five ecosites based on hydrologic and nutrient regimes (Beckingham and Archibald 1996). Lichen (a) ecosites have xeric to subxeric hydrologic and poor to very poor nutrient regimes. *Pinus banksiana* dominates with *Arctostaphylos uva-ursi* (L.) Spreng. (common bearberry), *Vaccinium vitis-idaea* L. (bog cranberry), *Vaccinium myrtilloides* Michx. (blueberry) and lichen in the understory. Low bush cranberry (d) ecosites have mesic hydrologic and medium nutrient regimes. Typical species are *Populus tremuloides*, *Picea glauca*, *Rosa acicularis* Lindl. (prickly rose), *Viburnum edule* (Michx.) Raf. (low bush cranberry), *Shepherdia canadensis* (L.) Nutt. (Canada buffaloberry), *Rubus pubescens* Raf. (dewberry), *Aralia nudicaulis* L. (wild sarsaparilla), *Cornus canadensis* L. (bunchberry) and *Elymus innovatus* Beal (hairy wild rye). Blueberry (b) ecosites, with submesic hydrologic and medium nutrient regimes, have elements of lichen (a) and low bush cranberry (d) ecosites. Labrador tea – mesic (c) ecosites have mesic hydrologic and poor nutrient regimes; typical species are *Pinus banksiana*, *Picea mariana*, *Ledum groenlandicum* Oeder. (Labrador tea), *Vaccinium vitis-idaea*, *Vaccinium myrtilloides*, various mosses and *Cladina mitis* (Sandst.) Hale & W. Culb.

(reindeer lichen). Dogwood (e) ecosites have subhygric hydrologic and rich nutrient regimes, and like low bush cranberry (d) ecosites have *Populus tremuloides* and *Picea glauca* overstories, with *Populus balsamifera* becoming more prominent. Understory species are similar to low bush cranberry (d) ecosites with addition of *Lonicera involucrata* (Richards.) Banks (bracted honeysuckle), *Cornus stolonifera* Michx. (red osier dogwood), *Mertensia paniculata* (Ait.) G. Don. var *paniculata* (tall lungwort), *Calamagrostis canadensis* (Michx.) Beauv. (marsh reed grass), ferns and horsetails.

3.2 Research Site Descriptions And Experimental Design

LFH mineral soil mix and peat mineral soil mix treatments were studied at previously established research sites (Table 2.1). Sites differed in age, substrates cover soils were placed on, salvage and application depths and source of LFH mineral soil mix and peat mineral soil mix. Multiple year data were used to examine temporal effects.

3.2.1 South east dump woody debris site

South east dump (SE dump) is a saline sodic overburden pile at Suncor, 25 km north of Fort McMurray (Brown 2010, Brown and Naeth 2014). The 70 by 300 m study area is mid slope, facing east southeast. A complete randomized design has six *Picea mariana* and *Populus tremuloides* woody debris treatments on LFH mineral soil mix and peat mineral soil mix and controls without woody debris. Only the controls were examined in this study. Treatments are replicated six times, with 36 experimental units (10 by 30 m) and 5 m buffers, in two rows separated by a 10 m buffer (Figure 2.1). Slopes in the bottom row (6 to 10 %) are steeper than in the top (2.5 to 6 %) (Appendix A.1).

Soil covers were applied in November 2007. A 100 cm cap of clean overburden separated treatments from saline sodic overburden. LFH mineral soil mix was salvaged to 20 cm, stockpiled 3 months, and applied at 20 cm over 30 cm of B and C horizon mixed subsoil. LFH mineral soil mix was salvaged from mesic b and d ecosites with *Populus tremuloides*, *Picea glauca* and *Pinus banksiana* (Meaney 2012). Peat mineral soil mix (30 cm) was applied on clean overburden; no information on peat mineral soil mix was obtained. Materials were spread with a D6 Caterpillar bulldozer. Plots were fertilized in June 2008 with 23.5:25:8 (nitrogen:phosphorus:potassium) fertilizer at 300 kg / ha with a fixed wing aircraft. Fertilizing (31.5:16:5) continued annually from 2009 to 2011 at 250 kg / ha.

3.2.2 Aurora sand and peat-sand sites

Syncrude Aurora North Mine (Aurora) is 61 km north of Fort McMurray (Mackenzie 2012a). Cover soils were applied to two sites with sand and peat-sand substrates, located 350 m apart on a lower north facing slope on lean oil sand overburden. Slope was 10 to 20 % on the sand site and 5 to 10 % on the peat-sand site. The sand site had 1 m of sand over lean oil sand; the peat-sand site had 1 m of 50 % sand and 50 % peat from a fen.

LFH mineral soil mix at 10 and 25 cm salvage and 10 and 20 cm application depths were each replicated three times in 15 by 70 m strips in a complete randomized design in March 2006 (Figures 2.2, 2.3). Since only 25 cm salvage treatments were used in this study, treatments are denoted as 10 cm and 20 cm LFH mineral soil mix. A control with no LFH mineral soil mix at the peat-sand site represented standard reclamation practices on sandy substrates. There was no control at the sand site as these are not left bare due to erosion risk. LFH mineral soil mix was applied with D8R and D6LPG Caterpillar crawler tractors.

LFH mineral soil mix was salvaged from *Pinus banksiana* and *Pinus banksiana - Populus tremuloides* stands in September 2005 with a D7 Caterpillar crawler tractor and stored for 6 months in 2 to 3 m high and 4 to 6 m wide windrows. Timber was harvested in summer 2005, 4 to 6 months earlier. Soils of *Pinus banksiana* stands were typically Orthic Eutric Brunisols with 2 cm of LFH; soils of *Pinus banksiana-Populus tremuloides* stands were Eluviated Eutric Brunisols with up to 8 cm of LFH. Soil properties and plant communities of the stands were not similar enough to be grouped and there was not enough of either type to apply to sand and peat-sand sites. Thus, soil from *Pinus banksiana* stands was placed on the peat-sand site and soil from *Pinus banksiana - Populus tremuloides* mixedwood sites was placed on the sand site.

The 25 cm salvage depth is not representative of current practices. Syncrude's 2007 operating approval (Alberta Environment 2007a) specifies a maximum salvage depth of 15 cm for a and b ecosites, which these donor sites likely were.

The maximum salvage depth for other ecosites is 30 cm meaning salvage depths at the other research sites are representative of current practices. The 25 cm salvage depths at Aurora were chosen for comparison to other sites.

3.2.3 W1 overburden storage facility

W1 overburden storage facility (W1 dump) is at Syncrude base mine 40 km north of Fort McMurray (Mackenzie 2006, Mackenzie and Naeth 2010). It is a saline sodic overburden dump covered with 90 cm of secondary material (fine textured, non-saline, non-sodic overburden) in February 2004. Saline sodic overburden is marine shale of the Clearwater Formation with electrical conductivities >4 dS / m and sodium adsorption ratios of 18 to 37 (Fung and Macyk 2000).

The site is on a mid to upper slope with southeast aspect. There are three 12 to 46 m long slopes (6 to 16 %) and two 12 to 46 m long benches (0 to 6 %) (Appendix A.2). The 300 by 150 m study area has a complete randomized design with four treatments, each replicated three times (12 experimental units) (Figure 2.4). Treatments are 10 and 20 cm applications of LFH mineral soil mix and peat mineral soil mix in 25 by 150 m strips. There are no buffers due to equipment size constraints. Peat mineral soil mix was applied to the remaining overburden.

LFH mineral soil mix, consisting of LFH layers (mean depth 7.5 cm), eluvial A, transitional AB and illuvial B horizons, was salvaged to 20 cm and stockpiled in November 2003. Peat mineral soil mix was obtained by stripping a peat layer > 40 cm deep and mineral soil below in November 2003. Cover soils were applied February 28 and 29, 2004. Average depths for 10 and 20 cm treatments were 12.8 and 21.3 cm, respectively. D10 Caterpillar bulldozers were used for stripping and spreading. Large frozen peat lumps were flattened with pipes in June 2005 on peat mineral soil mix. In fall 2005, after two years of vegetation data collection, *Populus tremuloides* and *Picea glauca* seedlings were planted (Vassov 2012, Mackenzie 2012b).

The LFH mineral soil mix donor site was vegetated with *Populus tremuloides,* and a few *Picea glauca* and associated understory species including *Salix* spp. (willows), *Rosa acicularis*, *Calamagrostis canadensis*, *Carex* sp. L. (sedges), *Fragaria virginiana* Duchesne ssp. *glauca* (S.Wats.) Staudt. (wild strawberry), *Epilobium angustifolium* L. ssp. *angustifolium* L (fireweed), *Aster ciliolatus* Lindl.

(Lindey's aster) and *Petasites palmatus* (Ait.) A. Gray (palmate-leaved colts foot). Peat mineral soil mix was salvaged from a site dominated by *Salix* sp., *Ledum groenlandicum*, *Oxycoccus microcarpus* Turcz. (small bog cranberry), *Vaccinium vitis-idaea*, *Carex* sp. and *Calamagrostis canadensis.*

3.2.4 Mildred Lake Settling Basin

Mildred Lake Settling Basin (MLSB), a tailings dyke surrounding a tailings pond, is at Syncrude base mine. Three treatments were applied at Cell 18 toe berm and two at Cell 16 to 19 beach (Cell 16) (Lanoue and Qualizza 2000) (Figure 2.5). Treatment and control areas were 50 by 50 m. LFH material was salvaged in August 1998 at an average 7.8 cm depth from a dry upland *Populus tremuloides* dominated pre-mining area (deforested 1996) and windrowed a few days later. Undisturbed soil was an Orthic Gray Luvisol with shallow (0 to 5 cm) LFH and sandy Ae horizons. Although less mineral material was expected to be mixed with LFH at this salvage depth, the term LFH mineral soil mix was used.

LFH mineral soil mix was placed on Cell 18 in late August 1998 over peat mineral soil mix placed in 1997 (Pollard 2001). In mid January 1999, LFH mineral soil mix was placed at remaining areas of Cells 18 and 16, using Caterpillar 777 and 789 trucks and bulldozers. Cell 18 treatments are summer and winter placement of 11 to 13 cm of LFH mineral soil mix (3 replicates) over 18 cm peat mineral soil mix over 35 cm secondary and a control with the same 18 cm peat mineral soil mix over 35 cm secondary (2 replicates) (Figure 2.5). Summer placements are east of winter ones. Slopes are 11 to 14 %, facing north to north northeast (Appendix A.3). Cell 16 treatments are winter placement of 18 cm of LFH mineral soil mix over 23 cm secondary material and 18 cm of peat mineral soil mix over 23 cm of secondary, with no replicates (Figure 2.5). Cell 16 slopes are 1 % or less. Effect of placement season is confounded by stockpiling since stockpiling significantly affects seed bank viability (Mackenzie 2012a). Winter treatments were established using stockpiled material, summer treatments were direct placed. Thus direct placement and short term stockpiling are compared.

Peat mineral soil mix treatments were fertilized at 500 kg / ha with 10:30:15:4 (nitrogen:phosphorus:potassium:sulfur) fertilizer and seeded to barley in 1998 at Cell 18 and 1999 at Cell 16 (McMillan et al. 2007). Trees were planted at Cell 16 in September 2000 (1:1 *Populus tremuloides* – *Picea glauca* mix at 2,019 stems / ha) and at Cell 18 in August 2005 (1:1.1 *Populus tremuloides* and *Pinus banksiana* at 1,981 stems / ha) (Yarmuch 2013).

3.3 Vegetation Assessment

Vegetation was assessed at W1 dump, SE dump and Aurora sand and peat-sand sites August 10 to 19, 2010. At MLSB species richness was determined on August 18 and 19, 2010 and vegetation was assessed July 15 to 17, 2011. Quadrats were placed along transects to measure canopy cover by species; ground cover of live vegetation, litter, bare ground, woody debris, rocks (> 2 cm diameter) and moss; and woody species density. Although grass and forb density are important in early stages of reclamation to examine germination, emergence and recruitment, it becomes more difficult to determine and less significant with time; canopy cover is more effective later as it better reflects environmental conditions (Elzinga 1998). Only plants rooted in the quadrat were counted, except for *Arctostaphylos uva-ursi* because it is low growing with extensive trailing branches. Shrubs rooted directly beside the quadrat and providing some cover were noted and included in species richness.

Each quadrat was given a biomass rating from 1 to 3 based on vegetation volume by visualizing how much of a bag would be filled by clipped vegetation. Rectangular 0.5 m^2 quadrats were used based on vegetation size and distribution and were orientated with the long edge parallel to the slope to reduce variability and increase precision (Elzinga 1998). Number of transects and quadrats varied with site and was based on past sampling, species area curves and feasibility. At SE dump 15 permanent quadrats were established in 2008 in three columns with five rows 5 m apart. In 2010, 7 permanent quadrats on controls (no woody debris) of LFH mineral soil mix and peat mineral soil mix were randomly selected (84 quadrats, 1 per 43 m^2). In 2011, 7 to 9 permanent quadrats from the third and fifth rows were assessed. Quadrats were not permanent at the remaining sites and were delineated using 100 m tapes.

At W1 dump 4 treatments were assessed in 2 transects with 20 m quadrat spacing (14 quadrats per experimental unit). Transects, 8 and 16 m from south corners of experimental units, ran parallel to the slope (168 quadrats, 1 per 268 m^2). At Aurora 10 and 20 cm LFH mineral soil mix and control were assessed in 1 to 2 transects with 7 m quadrat spacing (9 to 18 quadrats per experimental unit) at the peat-sand site and 1 transect with 6 m quadrat spacing (11 quadrats per experimental unit) at the sand site. Transects ran parallel to the slope, beginning 6 m from the eastern edge of the experimental unit, or 4 and 10 m for two transects. At Aurora 169 and 66 quadrats were assessed at peat-sand and sand sites, respectively, 1 quadrat per 58 to 116 m^2, respectively.

At MLSB all treatments were sampled, including LFH mineral soil mix over peat mineral soil mix (summer and winter placements) and LFH mineral soil mix over secondary prescriptions (winter placement) and peat mineral soil mix controls. Three transects ran across slope (quadrat orientation same as other sites) at 14, 31 and 42 m from the upper edge of plots. At Cell 16, with negligible slope, distances were measured from the northern edge of the plots. A 10 m quadrat spacing was used (12 quadrats per experimental unit) for a total of 120 quadrats at Cells 16 and 18; 1 quadrat per 208 m^2. Grasshoppers had grazed vegetation so cover was assessed as though plants were not eaten.

Systematic walk throughs in each experimental unit were performed to locate species not found in the quadrats. Surveyors separated by a distance of 5 m walked slowly down the experimental units and scanned for new species. In 2011 assessors counted the number of times each species was found during the systematic walk throughs at SE dump and MLSB.

3.4 Slope, Aspect And Meteorological Characterization

Slope and aspect of each experimental unit at SE dump, W1 dump and MLSB were measured with a clinometer and a compass, respectively. Slope position of each quadrat was determined based on its location along the transect. General slope data for Aurora sites were obtained from Mackenzie (2012a).

Rainfall data were obtained from meteorological stations on or near each of the research sites. Meteorological stations were installed at SE dump in 2009, Aurora sand site in 2006, W1 dump in 2004 and Cell 18 in 2003. Rainfall was measured using tipping bucket rain gauges; snowfall was not accurately captured. For this reason growing season rainfall rather than annual precipitation was discussed. Long term normals (30 year averages) were obtained for the Fort McMurray airport climate station. Ideally data for individual years at the Fort McMurray airport station would be compared to long term normals to determine if study years were wetter or dryer than normal, but data were not available beyond 2007 and thus this was not possible. Comparison of rainfall at each site to long term normals measured at the airport was the closest approximation possible given data contraints but was inherently flawed by geographical variability.

3.5 C-S-R Classification

The C-S-R (competitive-stress tolerant-ruderal) system classifies plant species by adult strategy of response to stress and disturbance (Grime 1974, Hodgson et al. 1999). Under low stress and high disturbance species tend to ruderality (R); under high stress and low disturbance they tend to tolerance (S); under low stress and disturbance they tend to be competitive (C). Under intermediate stress and disturbance species are classified as intermediate types (C/CR or R/CR) representing relative importance of the three attributes. C-S-R functional types can be represented graphically by a triangular diagram with each position defined by a three part C,S,R coordinate.

Community examination can be based on roles species play, rather than species classification and taxonomy, which simply reflects evolutionary ancestry of a plant (Hunt et al. 2004). The C-S-R system has been used to assess temporal changes in plant functional groups and their mechanisms in grasslands in Poland (Dzwonko and Loster 2007) and the effect of planted tree species on herbaceous vegetation at a reclaimed oil shale opencast mine in Estonia (Pensa et al. 2008).

In other studies, once C-S-R functional type of each species was established, plant communities were assigned a functional signature which is compared among communities (Hunt et al. 2004). Since not all species were classified due to difficulties in collection, this analysis was not conducted. Instead only C-S-R types of dominant species on each treatment in each year were examined.

3.5.1 Data collection and laboratory methods

Over 1,000 species have been classified in the United Kingdom (Hunt et al. 2004). Less work has been done in North America; many species at the research sites required classification. Variables needed to classify species into C-S-R functional types are dry matter content, dry weight and leaf area, canopy height, flowering period, flowering start and lateral spread (Hodgson et al. 1999). A spreadsheet is used to compute functional type (http://people.exeter.ac.uk/rh203/allocating_ csr.html). Although variables were developed for herbaceous vegetation, the approach could be used with shrubs (Hodgson et al. 1999) and woody plants have been assigned functional types (Grime et al. 2007). Since no work is published on classifying shrubs, herbaceous plant variables were used.

Plant samples were collected June 22 to July 6, 2010 and June 20 to 24, 2011 from SE dump, W1 dump, MLSB and natural forests south of Fort McMurray. Samples of 5 to10 robust, unshaded, undamaged leaves were taken from multiple flowering plants and multiple locations per plant; for rare species, fewer leaves were collected and all were from one plant (Wilson et al. 1999, Vaieretti et al. 2007). For leaf characterization, 3 collections per species from different geographic places are recommended to maximize intra-specific variability related to climate and geology; this was not achieved. Samples were refrigerated up to 4 days in damp paper towels in plastic bags until analysis (Wilson et al. 1999).

Specific leaf area, fresh and dry weight and dry matter content were determined for each leaf. Specific leaf area is the ratio of leaf area to leaf dry mass; dry matter content is the ratio of leaf dry mass to fresh mass (Garnier et al. 2001). Leaves were blotted on paper towel and petioles removed, including petiolules that separate leaflets for compound leaves, such that only laminar material was used to determine fresh and dry weight (Wilson et al. 1999). Grass leaf blades (above the collar) were measured and leaf sheaths discarded. Fresh weights were likely underestimated as storage was imperfect and leaves had wilted prior to measurement. Leaves were oven dried individually in paper envelopes at 70 °C for 48 hours then weighed. Transparency paper with a 1 by 1 cm grid was used to measure leaf area in 2010. With finely divided leaves, area occupied by the leaf was measured and halved to account for spaces between leaf tissue. Specific areas of leaflets of compound leaves were added. In 2011 the WinFolia software program (Regent Instruments Inc.) was used to measure leaf area of scanned leaves (except grasses which were measured with transparency paper).

Information on lateral spread and canopy height was mainly from Moss (1994) and Tannas (2003a, 2003b, 2003c). Flowering start and period references were Cormack (1977), Wilkinson (1990), Haeussler et al. (1990), Wilkinson (1999), Royer and Dickinson (2007) and Smreciu (2012). Information disparities were common, so earliest start and longest range of months were used.

To account for fresh weight losses, sensitivity of calculated C-S-R types to change in dry matter content was assessed, as with less wilting, fresh weight would be higher and dry matter content (fresh weight / dry weight) lower. If calculated C-S-R type changed when dry matter was decreased, both C-S-R type with fresh weight and that with lower dry matter were recorded. The two types were almost always adjacent in the C-S-R triangle. C-S-R types might also be sensitive to changes in lateral spread as it was often difficult to classify species into 1 of 6 categories. If changing this category made more than one calculated C-S-R type possible, both were recorded. They were also almost always adjacent in the C-S-R triangle.

3.6 Vegetation Data Analyses

Vegetation data from 2010 and 2011 were combined with data from previous research at the respective sites (Mackenzie 2006, Brown 2010, Mackenzie and Naeth 2010, Mackenzie 2012a, Brown and Naeth 2014). Table 2.2 provides number and size of quadrats used each year.

Species canopy cover data were used to calculate species richness, native species richness, Smith Wilson evenness and Shannon index of diversity. Total cover was tabulated for each quadrat from individual species covers; hence quadrats could have canopy covers > 100 %. Traces were set at 0.01 % in calculations and statistics. Woody plant density was calculated as total shrubs and trees in quadrats divided by number of quadrats surveyed per experimental unit to account for differences in numbers of quadrats. Values were converted to a per m^2 basis by multiplying by 10 for 0.1 m^2 quadrats or 2 for 0.5 m^2 quadrats.

At Cells 16 and 18, difficult to distinguish specimens of *Agropyron trachycaulum* (Link) Malte (slender wheatgrass), *Agropyron repens* (L.) Beauv. (quack grass) and *Agropyron hirtiflorus* (A.S. Hitchc.) Bowden were kept separate in the final data set, as they all occurred. *Medicago* specimens at Cells 16 and 18 were called *Medicago sativa* L. (alfalfa) although *Medicago falcata* L. (yellow lucerne) was observed in surrounding areas. *Fragaria vesca* L. (woodland strawberry) may have occurred but was lumped with *Fragaria virginiana* as identification differed among assessors. Both *Prunus pensylvanica* L.f. (pin cherry) and *Apocynum androsaemifolium* L. (spreading dogbane) were present at Aurora but mistakenly called *Prunus pensylvanica*, potentially making its cover values too high since no correction was possible. This occurred mainly at the Aurora sand site where both species were found in the past; *Apocynum androsaemifolium* was not previously found at the Aurora peat-sand site and thus In 2010 all *Prunus pensylvanica* at the Aurora peat-sand site were likely correctly identified.

Woody plant density was not always recorded and was estimated based on cover and density relationships for that treatment. 2010 *Rubus ideaus* L. (wild red raspberry) density may have been over estimated. Multiple stems emerge from the same spot; in 2010 some assessors counted all stems while others grouped them as one plant. Thus densities > 4 were divided by 4 based on an estimate that each plant had 4 stems emerging from one spot. In 2008, 2009 and 2011 assessors counted all stems emerging from a single spot as one plant.

3.6.1 Species richness and species composition

Experimental unit richness was obtained by making a list of all species found in each experimental unit, quantifying them, and averaging these values. Treatment richness was obtained by combining species lists for experimental units and removing duplicates. Treatment richness values are higher than experimental unit species richness values and are more accurate but cannot be analyzed statistically. It was qualitatively assessed to determine whether trends were similar to experimental unit richness. Total species richness per treatment was calculated by combining species richness lists from each year and was analyzed qualitatively. Native species richness was calculated by subtracting known non-native species from species richness. Unknowns were included in native species richness.

Assessors sometimes identified plant taxonomic levels differently. For example, in year 1 at SE dump two *Lathyrus* species were recorded as *Lathyrus* spp. L. (pea vine); in later years they were differentiated as *Lathyrus ochroleucus* Hook.

(cream pea) and *Lathyrus venosus* Muhl. (veiny pea), elevating species richness. There were at least ten similar issues with other genera. To avoid simplification by grouping species into genera, a most possible approach in which the most possible species were included was used instead of a most certain approach, which would have excluded species that were classified differently over time from the richness tally. Efforts were made to avoid double counting and over inflation. If *Melilotus officinalis* (L.) Lam. (yellow sweet clover) and *Melilotus alba* Desr. (white sweet clover) were in an experimental unit, *Melilotus* spp. was removed from the list. If *Poa palustris* L. (fowl blue grass) and *Poa pratensis* L. (Kentucky blue grass) were on the list, *Poa* spp. was removed; if *Rubus idaeus* and *Rubus pubescens* were listed *Rubus* spp. was removed; if *Lathyrus venosus* and *Lathyrus ochroleucus* were listed *Lathyrus* spp. was removed. *Salix* spp., *Carex* spp. and other plants identified to genus were included in the richness tally unless specified above. Dicotyledonous spp. was removed as they were likely juvenile forms of species in the vicinity; unknown species were included.

Number and size of quadrats were inconsistent over time affecting species richness as it is a function of area sampled, with more quadrats resulting in higher richness. The relationship is generally a curve which levels off, reaching an asymptote (Magurran 2004). 2010 and 2011 data were collected at a lower intensity than previous years (Table 2.2), thus smaller species richness was expected. Therefore systematic, detailed walk throughs were conducted to find species missed by quadrats. Other differences are noted in Table 2.2.

Richness data were treated differently for cover soil type and year comparisons. Cover soil comparisons were within years, with sampling intensity generally the same. For year to year comparisons sampling intensity differed among years, thus rarefaction was used to determine if sufficient quadrats were used. In 20 to 40 % of cases enough quadrats were sampled; in 60 to 80 % there were not enough and estimated total richness (Chao 2 estimate using bias corrected formula (Colwell 2013)) was used to compare treatments among years (walk through data not included). Estimated values were determined for experimental units and values averaged per treatment. Treatments were compared with means and standard deviations rather than with statistics. Rarefaction was done with EstimatesS software (Version 9 by Colwell 2013).

For comparisons among cover soil types there were a few instances where number of quadrats was not equal for all experimental units at a site in a single year (Table 2.2). For example, at Aurora number of quadrats per experimental unit differed among treatments in 2010. Because a walk through was done for all treatments, no adjustment of data (rarefaction) was required; the walk through equalized differences in species richness between experimental units that might have been due to a different number of quadrats. A walk through was expected to capture extra species more effectively than additional quadrats due to uneven and disjointed distribution of rare species. For 2010 and 2011 cover soil type comparisons walk through data were added to quadrat data prior to comparison.

Multiple assessor issues that affected species composition data were treated differently than for species richness. A matrix with species names as columns and treatments in different years as rows was constructed for multivariate analysis. This matrix was affected by differences in how plants were identified (genus or species) because it results in zeros when species names change. Species appear to disappear when they have not and were listed under another more or less specific name. Plants identified to genus in year 1 and identified to species in later years, were grouped as a genus (e.g. *Lathyrus ochroleucus* and *Lathyrus venosus* were combined to *Lathyrus* spp.). These adjustments were made on a site basis; different species were grouped into genera based on naming conventions for a given year. Unknown species were included.

3.6.2 Smith-Wilson evenness and Shannon index of diversity

Smith-Wilson evenness was calculated to complement species richness discussion and account for species abundance. Evenness metrics show different relative abundances on a 0 (maximally uneven) to 1 (even) scale (Maurer and McGill 2011). Communities dominated by one or few species have lower evenness than those with lower abundances of many species. Cover by species was averaged across quadrats in an experimental unit and evenness calculated. An index of diversity was calculated as it combines richness and evenness into a single value reflecting number of species and evenness with which species were distributed. Species cover averaged across quadrats in an experimental unit was used to calculate Shannon index of diversity; natural logs were used (Magurran 2004). For evenness and diversity all plants in quadrats were included.

3.6.3 Species groups analysis

Analysis of community dynamics should include species types as not all species or functional groups are equivalent and can play different roles in an ecosystem. Per quadrat, species were grouped according to growth form (grass, sedge, rush, forb, shrub, tree, pteridophyte, moss / lichen) and origin (native, non-native) (Appendix A.3). Unknown species were removed from species group calculations and those identified to genus were included. Growth form and origin were from Moss (1994), Tannas (2003a, 2003b, 2003c) and Johnson et al. (1995). Group cover was calculated per quadrat and averaged per experimental unit.

3.6.4 Dominant species analysis

For each treatment, species composition was averaged across experimental units and average cover of each species was listed highest to lowest. Species with highest cover were considered dominant; two or three with similar cover were considered co-dominant. Subdominant species, those that occupied more space in quadrats than most, occupied > 5 % of total cover (proportion based). Rank abundance curves were used with the 5 % criterion to determine subdominant species. A rank abundance curve was generated for each treatment; the 5 % criterion generally corresponded to a natural break in the curve. In some cases, due to natural breaks, species just below or above 5 % were included or excluded. Most treatments had 1 to 5 subdominant species, although a few had up to 8. This is a small pool considering most treatments had 20 to 50 species, with some as low as 10 in earlier years.

Dominant and subdominant species were classified by successional stage (early, early to late, late), C-S-R functional type (competitor, stress-tolerator, ruderal, intermediates) (Hodgson et al. 1999, Hunt et al. 2004) and habitat (natural, natural and disturbed, disturbed) (Appendix A.4). Analysis was to determine if reclaimed sites were dominated by early successional or disturbance type species or whether late successional and natural type species were establishing. Habitat information was from Tannas (2003a, 2003b, 2003c), Moss (1994) and Johnson (1996). Successional stage information was difficult to find. The USDA Forest Service Plant Species Life Form database (2013) has detailed information for some species. Gerling et al. (1996) list successional stage of many species which did not correspond to the USDA database. Thus information from USDA and Gerling were ignored and judgement calls made on successional stages. Successional stages were assigned based on upland boreal forest. Boreal mixedwoods are dominated by *Populus tremuloides* or *Betula papyrifera* in early stages, *Picea mariana* or *Picea glauca* in mid stages and *Abies balsamea* in late stages (Macdonald 1995). Early succession refers to stand initiation, stem exclusion and likely beginning of canopy transition where shade tolerant trees take over from shade intolerant ones (Chen and Popadiouk 2002). Mid succession refers to canopy transition and late succession correlates to gap dynamics. Species only found in mid successional stages were difficult to identify and thus species are designated as early, early to late or late successional. Some classifications were based on those provided in boreal forest literature, especially early successional species; others were estimates.

3.7 Statistical Analyses

3.7.1 Univariate statistics

Two or three way ANOVAs were used to examine effect of cover soil type, application depth (W1 dump), age (except species richness and native species richness) and their interactions. Cover soil type, application depth and age were fixed factors. Analyzes were conducted using SAS statistical software (version 9.3, SAS Statistical Institute). Study sites were analyzed separately.

Three way ANOVAs were used for W1 dump to compare two cover soils (LFH mineral soil mix, peat mineral soil mix), two application depths (10, 20 cm) and four ages (years 1, 2, 3, 7). Species richness and native species richness were analyzed with two way ANOVAs within year. Differences in species richness between ages at all sites were discussed qualitatively after rarefaction analysis. For SE dump two way ANOVAs were used to compare two cover soils (LFH mineral soil mix, peat mineral soil mix) and examine temporal trends at four ages (years 1, 2, 3, 4). Two way ANOVAs were used for Aurora to compare five cover soils (10 and 20 cm LFH mineral soil mix on sand, 10 cm and 20 cm LFH mineral soil mix on peat-sand, peat-sand control) at four ages (years 1, 2, 3, 5). SE dump and Aurora species richness and native species richness were analyzed using one way ANOVAs within year. At Cell 18 one or two way ANOVAs were used to compare three cover soils (summer placed LFH mineral soil mix over peat mineral soil mix, winter placed LFH mineral soil mix over peat mineral soil mix, peat mineral soil mix over secondary) at two ages (years 12 and 13). At Cell 18 comparison among years was not possible as assessment methods differed. Data were not collected in 2010, thus rarefaction was not possible. Cell 16 data were qualitatively analyzed as there was only one replicate per treatment.

Prior to ANOVA, data were tested for normality and homogeneity of variance using Shapiro-Wilk and Levene's tests, respectively. Permutational analysis of variance (perANOVA) was used with non normal data (Anderson 2005). Proc mixed for heterogeneous variances in SAS was used for non homogeneous data (version 9.3, SAS Statistical Institute). The non-parametric Kruskal-Wallis test or Scheirer-Ray-Hare extension of the Kruskal Wallis test (Scheirer et al. 1976) were used when data were not normal and variances were not homogeneous. The Scheirer-Ray-Hare test was run in R (version 2.12.1, R Development Team). Transformation was unsuccessfully attempted to avoid non-parametric tests. Significance was determined at $p < 0.1$ since non-parametric tests are conservative with much lower power than parametric tests (Dytham 2011).

Post hoc tests after significant ANOVAs and PERANOVAs provided pairwise comparisons among treatments. Only planned comparisons were examined to reduce type 1 error, and the Bonferroni correction was applied. Post hoc tests for non-parametric tests were less straight forward. Significant results were found for one Scheirer-Ray-Hare test and since the interaction was not significant, post hoc tests were conducted using a SAS macro for multiple comparisons after a significant Kruskal-Wallis test (Elliott and Hynan 2011). The macro uses the Nemenyi test if sample sizes are equal and Dunn's test if samples sizes are unequal or ranks tie (Elliott and Hynan 2011); Dunn's test was used in this case.

The method of analysis in which treatments and ages were treated as factors was difficult to interpret when interactions were not significant. With significant interaction, post hoc tests were performed to determine whether treatments differed for each age. Without significant interaction, main effects were examined independently. The p-value for each main effect was calculated by pooling data from the other factor. For example, when analyzing cover soil type as a main effect, data for all ages were pooled and differences between cover soil types are shown but it is difficult to ascertain if treatments differ at each age. In these cases data were separated into each age and one way ANOVAs run for each after testing for normality and homogeneity of variance.

3.7.2 Multivariate statistics

Treatment differences for multivariate plant community data sets (growth form cover, species composition) were detected using permutational multivariate analysis of variance (perMANOVA). The perMANOVA detects treatment differences by analyzing the ratio of distances between groups (treatment effect) compared to distances within groups (noise) (Anderson 2005, Hamann 2011). Distances are measures of similarity between observations, calculated using the Bray Curtis distance measure as it is most commonly used with community data, which is typically non-normal and has many zeros. Once a distance matrix was generated from raw data, perMANOVA was performed. A benefit of perMANOVA is that it does not require normally distributed data. Conversion of raw data to a distance matrix eliminates having insufficient degrees of freedom for testing in a data set with more variables than observations.

Multivariate tests such as perMANOVA require homogeneous variances. Permutational analysis of multivariate dispersion (PERMDISP) was used to assess homogeneity of variance (Anderson 2004). The intent was to analyze treatment differences and temporal differences within treatments, but for all data sets age failed the homogeneity test, and data were split by year. Cover soil and application depth effects were assessed using perMANOVA for each year. Bonferroni corrected pair wise comparisons were conducted after significant perMANOVAs. Cell 18 data did not meet the requirement for balanced data and multivariate data could not be analyzed with perMANOVA. Thus growth form data were split into variables (grass cover, sedge cover) for individual ANOVAs.

NMDS ordinations were used to verify significant perMANOVA results were due to locations in multivariate space, not relative variances and assess changes in species composition and cover over time. Ordinations showed associated species or groups and treatments. Ordinations were run using ecodist library in R (version 2.12., R Development Core Team). NMDS relies on a distance matrix;

Bray-Curtis dissimilarity was used. NMDS products, ordination diagrams, show plot similarity, inferred by dot proximity (Hamann 2011). The process is iterative with a result calculated multiple times to minimize stress. A random starting configuration was used. Stress values should be < 20 %, ideally < 10 % (Kruskal 1964 and Clarke 1993 cited in McCune and Grace 2002). In some cases more than two axes (dimensions) are needed. A scree plot of stress values associated with one to six dimensions was used to determine optimal number of dimensions.

Vectors were included in NMDS ordinations to show species or species groups with strong correlations with treatments. To minimize the number of vectors used in species composition ordinations, vectors with r values > 0.5 were included.

3.7.3 Meta-analysis

Data from four sites were combined and examined using meta-analysis to determine if cover soil effect was significant (Rosenberg et al. 2000). Separate analyses were run for each univariate parameter (woody plant density, species richness, native species richness, evenness, diversity, total cover, native cover, non-native cover) at each age (years 1, 2, 3). To assess long term trends an analysis was conducted using data from the final year for all sites.

Meta-analysis consisted of calculating effect size and associated variance for each study (experiment-control comparison), then calculating cumulative effect size and other summary statistics to test hypotheses (Rosenberg et al. 2000). Meta-win v2.0 software was used for all analyzes. Hedge's d, a measure of standardized mean difference, was used as the effect size measure and effect size variance calculated using a non-parametric method due to small sample size. For SE dump there was a single comparison between LFH mineral soil mix and peat mineral soil mix. At W1 dump 10 cm LFH mineral soil mix was compared to 10 cm peat mineral soil mix and 20 cm LFH mineral soil mix was compared to 20 cm peat mineral soil mix. For Aurora all four LFH mineral soil mix treatments (10 and 20 cm LFH mineral soil mix on sand and peat-sand) were compared to peat mineral soil mix control. At Cell 18 summer and winter LFH mineral soil mix placements were compared to the peat mineral soil mix control.

In the second step weighted resampling (non-parametric) meta-analysis was used. Effect sizes per study were combined in a weighted statistical model to account for sample variances. A random effects model was used to account for random variation in effect sizes and sampling error; fixed effects models only account for sampling error (Gurevitch and Hedges 1999). Bootstrapped, bias corrected 95 % confidence intervals were used to determine significance. If the confidence interval did not bracket zero the cumulative effect size was significant. Before conclusions were drawn, heterogeneity of effect sizes was considered. Total heterogeneity statistic, Q_T, was calculated and tested against a chi-squared distribution to determine if the significant variance among effect sizes was greater than expected by sampling error, in which case the other variables were examined. Q_T was not significant for any of the analyses. Publication bias, a frequent issue with meta-analysis, was not a problem as only data from our experiments were used.

4. RESULTS

4.1 Rainfall

Rainfall at SE dump in 2010 and 2011 (years 3 and 4) was 103.9 and 124.7 mm lower than the historical normal for the region (336 mm), respectively (Table 2.3). Monthly rainfall was lower than normal for all months except August 2010.

Rainfall at Aurora for 2007 to 2010 was lower than the regional normal (Table 2.4). The most pronounced difference occurred in 2007 (year 2), with 99 cm less rainfall than normal. The following 3 years had 61 to 89 cm below normal. Rainfall in May and July was lower than normal for all years, and in June, August, September and October was lower for 3 of 4 years.

W1 dump rainfall was lower than the regional normal in all years (Table 2.5). Pronounced deviations occurred in 2005 to 2009 (years 2 to 6) with 37 to 113 mm less rain and in 2011 there was 169 mm less. Rainfall in May, June, July, September and October was generally lower and higher than normal in August.

At MLSB Cell 18 rainfall in 2004 to 2007 (years 6 to 9) was 91.8 to 111.2 mm lower than the regional normal and 29.1 mm lower in 2008 (year 10) (Table 2.6). Rainfall in April, June, August, September and October was generally lower than normal and in July 2005, 2006 and 2007 it was higher.

4.2 Woody Plant Density

At SE dump woody plant density was significantly greater on LFH mineral soil mix than peat mineral soil mix in years 1, 2 and 3 but not year 4 (Table 2.7). Density increased steadily over time. Year 3 had significantly more woody plants than year 1; year 4 had significantly more than years 1, 2 or 3. The marked increase between years 3 and 4 was due to *Rubus idaeus* and *Salix* species.

At Aurora LFH mineral soil mix had significantly greater woody plant density than peat mineral soil mix in years 1, 2, 3 and 5 (Table 2.8). With 20 cm LFH mineral soil mix on sand, density was greater than with 10 cm on peat-sand at all ages. Other LFH mineral soil mix treatments had intermediate densities and were statistically similar to these treatments over time. Density on peat mineral soil mix levelled off by year 3 with significantly higher values in years 3 and 4 than year 1. With 20 cm LFH mineral soil mix on sand, density levelled off after year 2; there were no changes over time on other LFH mineral soil mix treatments.

At W1 dump woody plant density was significantly higher on LFH mineral soil mix than peat mineral soil mix in years 1 and 2; by years 3 and 7 large differences among replicates obscured trends (Table 2.9). There was no application depth effect. Overall there was a small decrease from years 1 to 2, a dramatic increase in year 3, with a decline in year 7; 20 cm peat mineral soil mix had the least change in year 3. The large increase in year 3 was due to planting *Populus tremuloides* and *Picea glauca* in fall of year 2 and to small seedlings in some quadrats which likely sprouted from seed from earlier established plants.

At Cell 18 LFH mineral soil mix had significantly more woody plants than peat mineral soil mix; summer and winter placements of LFH mineral soil mix were not significantly different (Table 2.10). LFH mineral soil mix at Cell 16 had numerically fewer woody plants than Cell 18. Peat mineral soil mix had similar woody plant densities at both sites, well below densities on LFH mineral soil mix. Trees were planted at Cells 16 and 18 in years 2 and 7, respectively.

4.3 Species Richness

Total species richness clearly differed on LFH mineral soil mix and peat mineral soil mix at MLSB (Table 2.11). In years 12 and 13 LFH mineral soil mix at Cell 16 had 66 species, peat mineral soil mix had 39. LFH mineral soil mix at Cell 18 had 73 species on summer and 84 on winter placements; peat mineral soil mix had 66. Differences at other sites were less noticeable. At W1 dump after 7 years LFH mineral soil mix had higher richness (100 species on 20 cm, 93 on 10 cm) than peat mineral soil mix (87 species on 20 cm, 90 on 10 cm). At SE dump richness on LFH mineral soil mix and peat mineral soil mix were 86 and 85, respectively, after 4 years. Aurora had 48 to 66 species after 7 years; total richness on LFH mineral soil mix on peat-sand was higher than on peat mineral soil mix, which had higher total richness than LFH mineral soil mix on sand.

As treatment richness (Appendices A.6, A.7, A.8, A.9) and experimental unit richness followed the same trends, only experimental unit richness is discussed hereafter. At SE dump species richness was significantly greater on LFH mineral soil mix than peat mineral soil mix in years 1 and 2, but not in years 3 and 4 (Table 2.12). Estimates of richness from rarefaction were highly variable among experimental units for both cover soils, with no observable changes over time.

At Aurora LFH mineral soil mix had significantly greater richness than peat mineral soil mix in year 1 and numerically greater richness in years 2 and 3 (Table 2.13). By year 5 only 10 cm LFH mineral soil mix on peat-sand had significantly more species than peat mineral soil mix. There were significantly more species on 10 cm LFH mineral soil mix on peat-sand than on 10 cm on sand; numerically it had more species than other LFH mineral soil mix treatments. Rarefaction estimates were the same or decreased over time on most LFH mineral soil mix treatments, except on 10 cm on peat-sand where richness was higher in year 5 than year 1. On peat mineral soil mix it increased from years 1 to 2 then levelled off.

At W1 dump cover soil type was significant in years 1, 2 and 3 but not year 7, with LFH mineral soil mix having higher species richness than peat mineral soil mix (Table 2.15). Application depth did not significantly affect richness in any year. Species richness (rarefaction estimates) increased in year 2 and remained constant into year 7 on 20 cm on both covers and 10 cm peat mineral soil mix. Richness on 10 cm LFH mineral soil mix was similar in years 7 and 1 based on standard deviations; richness in years 2 and 3 was higher than in years 1 and 7.

At Cell 18 cover soil type did not significantly affect species richness in years 12 or 13 (Table 2.16). At Cell 16 richness on LFH mineral soil mix was numerically similar to that at Cell 18 on both cover soils, and lowest on peat mineral soil mix.

4.4 Native Species Richness

At SE dump LFH mineral soil mix had significantly higher native species richness than peat mineral soil mix in years 1 and 2, but not years 3 and 4 (Table 2.12). There were no apparent trends over time for either cover soil as there was large variability in estimates of native species richness from rarefaction.

At Aurora native richness was significantly greater on LFH mineral soil mix than peat mineral soil mix in year 1, and numerically greater in years 2 and 3 (Table 2.14). Year 3 richness was significantly higher on 10 cm LFH mineral soil mix on peat-sand than peat mineral soil mix (numerically greater in year 5). Differences were not significant among LFH mineral soil mix treatments although in year 5, 10 cm on peat-sand had numerically higher richness than other treatments. Rarefaction estimates were static over time on LFH mineral soil mix, except on 10 cm on peat-sand in year 5 which was higher than in years 1 and 2. Richness on peat mineral soil mix was higher in years 3 and 5 than year 1.

At W1 dump LFH mineral soil mix had significantly higher native species richness than peat mineral soil mix in years 1, 2 and 3, but not in year 7; there were no significant differences with application depth (Table 2.15). Rarefied native species richness increased from years 1 to 2 on 10 cm LFH mineral soil mix but by year 7 was no higher than in year 1. On 20 cm LFH mineral soil mix and 10 cm peat mineral soil mix richness increased between years 1 and 2, remaining higher than year 1 thereafter. Rarefied native species richness on 20 cm peat mineral soil mix was substantially higher in years 3 and 7 than year 1.

At Cell 18 cover soil type effect on native species richness was not significant in years 12 or 13 (Table 2.16). LFH mineral soil mix richness was numerically greater at Cell 18 in year 13 and Cell 16 in years 12 and 13.

4.5 Evenness and Diversity

There were few significant differences in evenness with cover soil. At SE dump evenness was not significantly affected by cover soil, although it was numerically highest on peat mineral soil mix in year 3 (Table 2.17). On both cover soils it decreased significantly between years 1 and 2, increased significantly between years 2 and 3 and decreased significantly into year 4, which was not significantly different from years 1 or 2. At Aurora cover soil effect on evenness was not significant, with no treatment consistently highest or lowest (Table 2.18). In year 5 it was significantly lower than other years. At W1 dump evenness was not significantly different with cover soil, application depth or age (Table 2.19). It declined numerically over time on most treatments except on 10 cm peat mineral soil mix. At Cell 18 cover soil effects were not significant in year 13 (Table 2.20). Numerically evenness was lowest on peat mineral soil mix at Cell 16.

SE dump diversity was significantly greater on LFH mineral soil mix than peat mineral soil mix only in year 1 (Table 2.17), when it was significantly lower than in following years. W1 dump diversity was significantly greatest on LFH mineral soil mix in years 1 and 2 but not years 3 or 7 (Table 2.19). Application depth had no effect on diversity. There were significant fluctuations over time on both cover soils. On peat mineral soil mix diversity was significantly greater in year 7 than in year 1, while on LFH mineral soil mix it was equivalent in years 1 and 7. Aurora diversity was not significantly affected by cover soil and was significantly greater in year 3 than year 1, but similar in years 5 and 1 (Table 2.18). At Cell 18 diversity did not differ significantly with cover soil (Table 2.20). Numerically LFH mineral soil mix at Cell 16 was as diverse as all treatments at Cell 18. Cell 16 peat mineral soil mix had lower diversity than all other treatments at MLSB.

4.6 Total Cover

SE dump cover was significantly greater on LFH mineral soil mix than peat mineral soil mix in years 2 and 4 (Table 2.21). On LFH mineral soil mix cover increased significantly from year 1 to 2 and remained constant through to year 4. On peat mineral soil mix cover increased significantly from year 1 to year 2, peaked in year 3 then declined significantly; years 2 and 4 were equivalent.

In years 1, 3 and 5 at least one LFH mineral soil mix treatment at Aurora had significantly greater cover than peat mineral soil mix (Table 2.22). In year 1, 10 and 20 cm LFH mineral soil mix on sand had significantly greater cover than peat mineral soil mix. Year 3 cover was significantly greater on 20 cm LFH mineral soil mix on peat-sand than peat mineral soil mix. Year 5 cover on 20 cm LFH mineral soil mix on sand and peat-sand was significantly greater than on peat mineral soil mix; 10 cm LFH mineral soil mix on sand and peat-sand had numerically greater cover than peat mineral soil mix. In year 1, 20 cm LFH mineral soil mix on sand had significantly greater cover than 10 cm on peat-sand. In year 5, 20 cm LFH mineral soil mix on sand had significantly greater cover than 10 cm on sand. Numerically 20 cm LFH mineral soil mix on peat-sand cover was higher than 10 cm on sand. Total cover on all treatments except peat mineral soil mix increased over time at different rates. Only cover on 20 cm LFH mineral soil mix on peat-sand increased significantly in year 5; the others levelled off after years 2 or 3. Large standard errors may have obscured trends.

Total cover was significantly greater on 10 and 20 cm LFH mineral soil mix than on 10 and 20 cm peat mineral soil mix in years 1, 2 and 3 but not year 7 (Table 2.23). Cover was significantly greater on 20 cm of LFH mineral soil mix than 10 cm in years 1 to 3, with no significant differences between application depths of peat mineral soil mix in any year. Cover increased significantly on all treatments from years 1 to 3, with no significant increases in year 7.

Total cover at Cell 18 in year 13 was not significantly affected by cover soil despite large numerical differences between LFH mineral soil mix and peat mineral soil mix (Table 2.24). There was a substantial numerical difference in canopy cover on LFH mineral soil mix and peat mineral soil mix at Cell 16. Both Cell 16 treatments had canopy covers similar to peat mineral soil mix at Cell 18.

4.7 Native Species Cover

SE dump LFH mineral soil mix had significantly greater native species cover than peat mineral soil mix in years 2 and 4 (Table 2.21). On LFH mineral soil mix in year 1 it was significantly less than in other years, which were similar. Cover peaked on peat mineral soil mix in year 3, declining into year 4.

Aurora year 1 native cover was significantly greater on 10 and 20 cm LFH mineral soil mix on sand than peat mineral soil mix (Table 2.22); year 2 cover was significantly greater on 20 cm LFH mineral soil mix on sand. In years 3 and 5 cover on LFH mineral soil mix treatments was numerically greater than on peat mineral soil mix; differences were often statistically significant. Year 1 cover on 10 cm LFH mineral soil mix on sand was significantly greater than on peat-sand; numerically cover on 10 and 20 cm on sand was greater than 10 and 20 cm on peat-sand. Cover on LFH mineral soil mix did not differ in years 2 and 3. Year 5 cover was significantly greater on 20 than 10 cm LFH mineral soil mix on sand; numerically 20 cm on peat-sand had greater cover than 10 cm on sand. Cover on most LFH mineral soil mix increased significantly in the first five years but on peat mineral soil mix it did not change over time.

W1 dump native cover on 20 cm LFH mineral soil mix was significantly greatest in years 1, 2 and 3 (Table 2.23). Year 2 cover was significantly greater on 10 cm LFH mineral soil mix than peat mineral soil mix. Year 3 cover was significantly greater on 10 cm LFH mineral soil mix than 20 cm peat mineral soil mix. Year 7 cover on LFH mineral soil mix was numerically greater than peat mineral soil mix. Cover on 10 and 20 cm LFH mineral soil mix increased significantly from years 1 to 2 and 2 to 3 and on 10 cm in year 7. Cover on 10 and 20 cm peat mineral soil mix increased slowly, with no difference between years 1 and 2; year 3 cover was significantly greater than years 1 and 2; year 7 was significantly greatest.

At Cell 18 LFH mineral soil mix treatments had significantly greater native cover than peat mineral soil mix in year 13 (Table 2.24). At Cell 16 LFH mineral soil mix had numerically greater cover than peat mineral soil mix. Cover on LFH mineral soil mix at Cell 18 was almost double that on LFH mineral soil mix at Cell 16.

4.8 Non-Native Species Cover

At SE dump peat mineral soil mix had significantly greater non-native cover in years 2, 3 and 4 than LFH mineral soil mix (Table 2.21). Cover was constant over time on LFH mineral soil mix, at < 10.8 %. Peat mineral soil mix cover increased significantly between years 1 and 2, was constant into year 3, decreased significantly in year 4 but remained significantly greater than in year 1.

Aurora year 1 non-native cover was significantly lower on 20 cm LFH mineral soil mix on sand than on peat mineral soil mix (Table 2.22). No significant differences occurred later on. Year 5 cover on peat mineral soil mix was numerically greater than LFH mineral soil mix. Peat mineral soil mix cover increased significantly over time. Cover on 20 cm LFH mineral soil mix on sand was significantly greater in year 3 than years 1 and 2, numerically decreasing by year 4. Temporal change for other LFH mineral soil mix treatments followed the same trend.

At W1 dump years 1 and 2 non-native cover on 20 cm LFH mineral soil mix was significantly greatest (Table 2.23). Differences were not significant in year 3, with 20 cm LFH mineral soil mix numerically highest. Year 7 cover on 10 cm peat mineral soil mix was significantly greater than on 20 cm LFH mineral soil mix. Changes were slow on 10 and 20 cm peat mineral soil mix with significant increases in years 2 to 3. On 10 cm LFH mineral soil mix cover increased significantly in year 2 only, and on 20 cm increased significantly in year 2, remained constant in year 3, and was significantly lower in year 7 than year 3.

At Cell 18 LFH mineral soil mix had significantly less non-native cover than peat mineral soil mix in year 13 and at Cell 16 always had numerically less cover (Table 2.24). Cover on Cell 16 was similar to Cell 18 counterparts.

4.9 Meta-Analysis

LFH mineral soil mix had a significant, positive effect on woody plant density, species richness and native species richness, total cover and native species cover in years 1, 2, 3 and at final assessment (Table 2.25). LFH mineral soil mix had a significant positive effect on year 1 diversity, a significant negative effect on year 2 evenness and a significant negative effect on non-native species cover in the final assessment. Peat mineral soil mix had greater non-native cover than LFH mineral soil mix. Cumulative effect sizes increased over time for woody plant density and non-native cover suggesting differences were increasing over time. The difference between cover soils in species richness, native species richness, evenness and diversity decreased over time. Cumulative effect size for total cover and native species cover did not change between year 1 and the final assessment meaning differences between cover soils remained consistent.

4.10 Cover Of Growth Forms

Cover of 7 growth forms on cover soils at SE dump was significantly different in years 2, 3 and 4 (Table 2.26, Figures 2.6, 2.7). The X2 vs X3 ordination (Figure

2.7) showed a cluster of points for years 3 and 4 LFH mineral soil mix suggesting a distinct assemblage relative to years 1 and 2 and peat mineral soil mix. Most plots were otherwise clustered together, except some widely scattered year 1 plots, supporting the lack of significant differences in year 1. This was apparent on the X1 vs X2 ordination (Figure 2.6). The X2 vs X3 and X1 vs X2 ordinations showed year 2 plots for both cover soils clustered separately, supporting the significant difference in year 2. The same ordinations showed the shrub vector pointing towards year 3 and 4 LFH mineral soil mix plots. Grass and forb vectors were more associated with LFH mineral soil mix plots in years 2 and 3 while the pteridophyte vector was more associated with peat mineral soil mix plots. Sedge and moss vectors were difficult to interpret as they did not follow the same trend in both ordinations; the tree vector was short in both and is thus not important.

The year 1 dominant growth form on both SE dump cover soils was forbs; cover of other growth forms was < 1 % (Table 2.26). In year 2 forbs remained the dominant growth form, with moss being next most abundant on both cover soils. LFH mineral soil mix had noticeable amounts of other groups while on peat mineral soil mix cover of other growth forms was < 2 %. In year 3 forb cover still dominated but was declining on LFH mineral soil mix. Grasses and shrubs replaced mosses as the next most abundant groups on LFH mineral soil mix while mosses were still second most abundant on peat mineral soil mix. In year 4, LFH mineral soil mix was co-dominated by shrubs and forbs. Forb cover was similar on both cover soils; shrub and grass cover were higher on LFH mineral soil mix and moss cover was greater on peat mineral soil mix.

At Aurora cover soil failed the homogeneity of variance test for years 1, 2 and 3. Two dimensional NMDS supports this as some treatments were tightly clustered while others were widely dispersed (Figure 2.8). Year 1 peat mineral soil mix plots overlapped 10 and 20 cm LFH mineral soil mix on peat-sand, but not sand. Year 1 treatments were dominated by forbs; 10 and 20 cm LFH mineral soil mix on sand had highest forb cover (Table 2.27). Both 10 and 20 cm LFH mineral soil mix on sand had slightly higher shrub cover than peat mineral soil mix. Year 2 20 cm LFH mineral soil mix on peat-sand almost overlapped peat mineral soil mix, with other LFH mineral soil mix treatments further away. Cover of growth forms on 20 cm LFH mineral soil mix on peat-sand were similar to other LFH mineral soil mix treatments with a higher standard error for forb cover (dominant cover category) which may explain this pattern. Peat mineral soil mix had less forb, shrub and grass cover than LFH mineral soil mix. In year 3 cover soils did not overlap. Peat mineral soil mix had low total cover; grass and forbs co-dominated. LFH mineral soil mix had similar amounts of each growth form, except 20 cm LFH mineral soil mix on peat-sand which had more grass and forbs.

In year 5 some Aurora treatments were scattered on the ordination but less so than the previous year; year 5 data passed the homogeneity test. Cover soil effect was significant in year 5, with 20 cm LFH mineral soil mix on sand significantly different from peat mineral soil mix (Table 2.27) and furthest from it on two dimensional NMDS (Figure 2.8). Other LFH mineral soil mix treatments did not overlap peat mineral soil mix, indicating undetected statistical differences. Cover was low on peat mineral soil mix with forbs dominant. Forbs dominated 10 cm LFH mineral soil mix on sand and 20 cm on peat-sand; forbs and moss co-dominated other LFH mineral soil mix treatments. Forb cover was greater on 20 than 10 cm LFH mineral soil mixes on sand and peat-sand. Moss cover was greatest on 20 cm LFH mineral soil mix on sand, followed by 20 cm on peat-sand, 10 cm on peat-sand and 10 cm on sand. The 20 cm LFH mineral soil mix on peat-sand had greatest shrub cover; other LFH mineral soil mix had similar shrub cover. All vectors on the ordination except pteridophyte were associated with LFH mineral soil mix in years 3 and 5.

NMDS ordination showed a temporal progression at Aurora (Figure 2.8). Data form a circle, with earlier years transitioning into later years. Year 5 data for peat mineral soil mix was clustered with year 2 data for several LFH mineral soil mix treatments, showing the plant community on peat mineral soil mix developing more slowly than on LFH mineral soil mix.

Year 1 W1 dump data failed the homogeneity of variance test. Two of three three dimensional NMDS ordinations showed treatments as separate clusters (Figures 2.9, 2.10). Cover was low in year 1 (Table 2.28). In year 2 growth form covers differed significantly with cover soil for 10 and 20 cm depths. Differences were significant between 10 and 20 cm LFH mineral soil mix, but not peat mineral soil mix. Application depth failed the homogeneity of variance test in year 2, although ordinations support the findings. The 10 and 20 cm LFH mineral soil mix did not overlap on the ordinations; 10 and 20 cm peat mineral soil mix overlapped on the X2 vs X3 ordination (Figure 2.10). Peat mineral soil mix had low cover overall with forbs dominant. Forbs dominated LFH mineral soil mix, with cover on 20 cm almost double that on 10 cm. Other growth forms occurred in small amounts on LFH mineral soil mix. Year 3 cover soil failed the homogeneity of variance test. Cover soils did not overlap on ordinations, likely due to greater forb and moss cover on LFH mineral soil mix. Both 10 and 20 cm peat mineral soil mix overlapped on ordinations; 10 and 20 cm LFH mineral soil mix clustered separately on 2 of 3 ordinations. Moss and shrub cover were greatest on 20 cm LFH mineral soil mix. In year 7 cover soils had significantly different assemblages with no application depth effect. Ordinations did not completely support perMANOVA results as cover soils overlapped on the X1 vs X3 ordination (Figure 2.9). Forbs continued to dominate both cover soils, with greater cover on LFH mineral soil mix. Peat mineral soil mix had greater pteridophyte cover than LFH mineral soil mix.

NMDS ordinations for W1 dump (Figures 2.9, 2.10) showed a tight cluster for years 2, 3 and 7 for LFH mineral soil mix and years 3 and 7 for peat mineral soil mix, with earlier years scattered, suggesting assemblages were becoming similar with time on both covers. Within that cluster on the X2 vs X3 ordination (Figure 2.10) there was a separation between the two soil covers, with grass, forb, shrub and moss vectors pointing directly to LFH mineral soil mix plots, and the pteridophyte vector pointing to older peat mineral soil mix plots.

Multivariate testing was not conducted for MLSB Cell 18 growth form data for year 13 due to an unbalanced design; growth forms were analyzed separately. Winter placed LFH mineral soil mix had significantly greater shrub cover than peat mineral soil mix and summer placed LFH mineral soil mix had numerically greater shrub cover than peat mineral soil mix (Table 2.29). Tree cover was significantly higher on peat mineral soil mix relative to summer placed LFH mineral soil mix and numerically greater relative to winter placed LFH mineral soil mix. There were no significant treatment differences for grass, sedge, forb, moss or pteridophyte cover. Forb cover, the dominant growth form at Cell 18, was numerically greater on LFH mineral soil mix relative to peat mineral soil mix. Forbs dominated LFH mineral soil mix and peat mineral soil mix at Cell 16; cover was similar to peat mineral soil mix at Cell 18. Shrub cover on LFH mineral soil mix at Cell 16, while lower than on LFH mineral soil mix at Cell 18, was numerically greater than shrub cover on peat mineral soil mix at Cells 16 and 18.

Three dimensional NMDS ordinations for year 13 for Cells 16 and 18 showed LFH mineral soil mix at Cell 18 clustered separately from peat mineral soil mix, which was less tightly clustered (Figures 2.11, 2.12). Shrub, forb and sedge vectors were more associated with Cell 18 LFH mineral soil mix. Two ordinations (X1 vs X3, X2 vs X3, Figures 2.11, 2.12) showed LFH mineral soil mix at Cell 16 separate from LFH mineral soil mix at Cell 18. The tree vector pointed to LFH mineral soil mix at Cell 16, which had the highest tree cover. Cell 16 LFH mineral soil mix was well spaced from Cell 16 peat mineral soil mix on ordinations.

4.11 Species Composition

At SE dump cover soils had significantly different species compositions in years 2, 3 and 4, but not year 1. This was apparent on the X1 vs X3 NMDS ordination (Figure 2.13). The X2 vs X3 ordination (Figure 2.14) showed species associations most effectively. Vectors on NMDS ordinations represent most strongly associated ($r > 0.5$), but not necessarily dominant species. Peat mineral soil mix data (all ages) were located in the upper right hand portion of the ordination and LFH mineral soil mix in the bottom left. *Chenopodium album* L. (lamb's quarters), a non-native species, was associated with year 2 peat mineral soil mix and *Equisetum arvense* L. (common horsetail) with years 3 and 4 peat mineral soil mix. *Fragaria virginiana*, *Agropyron trachycaulum*, *Aster ciliolatus* and *Achillea millefolium* L. (common yarrow) were most associated with years 3 and 4 LFH mineral soil mix. These are native species to boreal forests; *Equisetum arvense, Fragaria virginiana, Agropyron trachycaulum* and *Achillea millefolium* are also commonly found in frequently disturbed environments such as ditches, road sides or waste ground. The X2 vs X3 ordination showed progression through time, with younger plots in the upper left hand corner and older plots in the lower right hand corner. *Corydalis aurea* Willd. (golden corydalis) was most associated with year 1 plots of both cover soils, while *Epilobium angustifolium*, *Sonchus arvensis* L. (perennial sow thistle) and *Rubus idaeus* were associated with years 3 and 4. *Corydalis aurea*, *Epilobium* *angustifolium* and *Rubus idaeus* are native, early successionals common in forest and disturbed environments. *Sonchus arvensis* is non-native.

Aurora data failed the homogeneity of variance test. The X1 vs X2 and X1 vs X3 ordinations of the three dimensional NMDS ordination (Figures 2.15, 2.16) show peat mineral soil mix loosely clustered on the left hand side, separate from LFH mineral soil mix in all years except year 1; 10 cm LFH mineral soil mix on peat-sand was located close to peat mineral soil mix in multivariate space. Within year LFH mineral soil mix overlapped considerably with no major differences in species composition; there were subtle differences. In year 1, 10 cm LFH mineral soil mix on peat-sand and sand clustered separately; in year 3, 10 cm LFH mineral soil mix on peat-sand clustered separately from 10 and 20 cm on sand. In year 5, 10 cm LFH mineral soil mix on sand clustered separately from other LFH mineral soil mix treatments. The X1 vs X2 ordination (Figure 2.15) showed a temporal progression, with young plots near the bottom and old near the top; the X2 vs X3 ordination (Figure 2.17) showed a temporal left to right progression.

Vectors on NMDS ordinations represent species most strongly associated with the data ($r > 0.5$); these species are not necessarily the dominant speciesfor a given treatment. Strong species associations on the X1 vs X2 ordination (Figure 2.15) included *Elymus innovatus*, *Epilobium angustifolium*, *Vaccinium myrtilloides*, *Carex* spp. and *Rosa acicularis* with years 3 and 5 LFH mineral soil mix (except 10 cm on sand), *Sonchus arvensis* with years 3 and 5 peat mineral soil mix and *Urtica dioica* L. (common nettle) with year 1 peat mineral soil mix. *Urtica dioica* was also strongly associated with peat mineral soil mix on the X1 vs X3 ordination (Figure 2.16), in this case with year 3 plots. Other associations on the X1 vs X3 ordination included *Agrostis scabra* Willd. (tickle grass) with year 3 peat mineral soil mix, moss/lichen and *Fragaria virginiana* with years 1 and 5 LFH mineral soil mix, and *Epilobium angustifolium* with years 2 and 3 LFH mineral soil mix (except 10 cm on peat-sand). The X2 vs X3 ordination (Figure 2.17), while not effective at differentiating treatments, showed *Oryzopsis pungens* (Torr.) A.S. Hitchc. (northern rice grass) with year 5 20 cm LFH mineral soil mix (sand and peat-sand) in addition to those mentioned. The only non-native species among these is *Sonchus arvensis*, which was associated with peat mineral soil mix. Other species associated with peat mineral soil mix (*Urtica* *dioica*, *Agrostis scabra*) are early successional and prefer natural and disturbed habitats. This description applies to several species associated with LFH mineral soil mix (*Epilobium angustifolium*, *Fragaria virginiana*). *Rosa acicularis*, associated with LFH mineral soil mix, tends to grow in natural and disturbed habitats and is early to late successional. *Elymus innovatus*, *Vaccinium myrtilloides*, *Carex* spp. and *Oryzopsis pungens* are early to late successional and tend to grow in natural, forest environments.

Year 1 W1 dump data failed the homogeneity of variance test. Treatments did not overlap on three dimensional NMDS ordinations (Figures 2.18, 2.19, 2.20), except 10 cm peat mineral soil mix and 20 cm LFH mineral soil mix on the X2 vs X3 ordination (Figure 2.20), meaning cover soils likely had different species compositions. In year 2 species composition differed significantly between 10 cm LFH mineral soil mix and 10 cm peat mineral soil mix and between 20 cm LFH mineral soil mix and 20 cm peat mineral soil mix. Ordinations showed this as well as a difference between cover soils overall and 10 and 20 cm LFH mineral soil mix not detected by statistics. Year 3 composition differed significantly with cover soil, with no significant application depth effect. Ordinations supported this, showing independent clusters of both cover soils, with no differentiation between 10 and 20 cm. Year 7 data failed the homogeneity of variance test. Ordinations showed differences between cover soils with no differentiation between 10 and 20 cm. The X1 vs X2 and X1 vs X3 ordinations (Figures 2.18, 2.19) showed a temporal change from years 2 to 7. The X2 vs X3 ordination (Figure 2.20) showed different rates of change in species composition on cover soils. LFH mineral soil mix year 1 data, on the left hand side, was separate from years 2, 3 and 7, which clustered in the centre. Years 1 and 2 peat mineral soil mix plots grouped in the upper left hand corner; years 3 and 7 plots grouped centre right.

Carex spp., *Taraxacum officinalis* Weber (common dandelion) and *Equisetum sylvaticum* were strongly associated with years 3 and 7 peat mineral soil mix at W1 dump (vector r value > 0.5). *Taraxacum officinalis* is non-native; *Carex* spp. and *Equisetum sylvaticum* L. (woodland horsetail) are native, early to late successionals preferring natural forest. *Agrostis scabra* (early successional) and dicot spp. were strongly associated with year 3 peat mineral soil mix and *Equisetum arvense* and moss (both early to late successional) were strongly associated with year 7 peat mineral soil mix; all are native and grow in natural areas (moss) or natural and disturbed areas (*Agrostis scabra*, *Equisetum arvense*). *Mertensia paniculata*, *Rosa acicularis*, *Achillea millefolium*, *Rubus idaeus*, *Elymus innovatus*, *Sonchus arvensis*, *Aster ciliolatus*, *Epilobium angustifolium*, *Vicia americana* Muhl. (wild vetch), *Agropyron trachycaulum*, *Fragaria virginiana* and moss were associated with years 2, 3 and 7 LFH mineral soil mix. The only non-native species was *Sonchus arvensis*. *Rubus idaeus*, *Epilobium angustifolium*, *Agropyron trachycaulum* and *Fragaria virginiana* are early successionals in natural and disturbed habitats. *Rosa acicularis* and *Achillea millefolium* are early to late successionals found in natural and disturbed habitats and.*Mertensia paniculata*, *Elymus innovatus*, *Aster ciliolatus*, *Vicia americana* and moss are early to late successionals in natural forests. A few species associated with both cover soils. *Atriplex subspicata* (Nutt.) Rydb. (salt rush), *Crepis tectorum* L. (annual hawksbeard) and *Potentilla norvegica* L. (rough cinquefoil) were strongly associated with year 3 20 cm peat mineral soil mix and year 2 LFH mineral soil mix and peat mineral soil mix. *Atriplex subspicata* and *Potentilla norvegica* are native species in natural and disturbed environments and *Crepis tectorum* is non-native. Moss was associated with years 3 and 7 LFH mineral soil mix and year 7 peat mineral soil mix. *Vicia americana* was associated with year 7 peat mineral soil mix.

At MLSB 2 of the 3 three dimensional NMDS ordinations (X1 vs X2, X1 vs X3; Figures 2.21, 2.22) showed clear cover soil differentiation. Species associated with LFH mineral soil mix were *Achillea millefolium*, *Agropyron hirtiflorus*, *Amelanchier alnifolia* Nutt. (saskatoon), *Aster ciliolatus*, *Aster conspicuus* Lindl. (showy aster), *Bromus inermis* Leyss. ssp. *inermis* Leyss (smooth brome), *Carex aenea* Fern (silvery-flowered sedge), *Carex* spp., dicot spp., *Elymus innovatus*, *Epilobium angustifolium*, *Erysimum cheiranthoides* L. (wormseed mustard), *Fragaria virginiana*, *Galeopsis tetrahit* L. (hemp nettle), *Galium triflorum* Michx. (sweet-scented bedstraw), moss spp., *Poa palustris*, *Rosa acicularis*, *Rubus idaeus*, *Schizachne purpurascens* (Torr.) Swallen ssp. *purpurascens* (T.) S. (false melic), *Symphoricarpos* spp. Duhamel (snowberry), unknown spp., *Urtica dioica*, *Viola adunca* J.E. Smith (early blue violet). Species associated with peat mineral soil mix were *Agropyron repens*, *Betula papyrifera*, *Bromus* spp. L. (brome grass), *Erucastrum gallicum* Willd. Schultz (dog mustard), *Hordeum jubatum* L. (foxtail barley), *Lotus corniculatus* L. (bird's foot trefoil), *Medicago sativa*, *Melilotus alba*, *Poa pratensis*, *Populus tremuloides*, *Salix* spp., *Sonchus arvensis* and *Taraxacum officinalis*. Two non-native species, *Bromus inermis* and *Galeopsis tetrahit*, associated with LFH mineral soil mix. *Agropyron repens*, *Erucastrum gallicum*, *Lotus corniculatus*, *Medicago sativa*, *Melilotus alba*, *Poa pratensis*, *Sonchus arvensis* and *Taraxacum officinalis* associated with peat mineral soil mix. Other than non-natives, others associated with peat mineral soil mix were native tree and shrub species (*Betula papyrifera*, *Populus tremuloides*, *Salix*) and two grasses, one may be early to late successional (*Bromus* spp.) and the other early successional in natural and disturbed places (*Hordeum jubatum*). There were no tree species associated with LFH mineral soil mix; there were four native shrubs. Some grow in forest and disturbed environments (*Rosa acicularis*, *Rubus idaeus*), others in forests (*Amelanchier alnifolia*, *Symphoricarpos* spp.). *Rosa acicularis*, *Amelanchier alnifolia* and *Symphoricarpos* spp. are early to late successional. Others associated with LFH mineral soil mix are native, early and early to late successional forbs and graminoids, some grow in forest and disturbed areas, others prefer forest. Moss was associated with LFH mineral soil mix; it is native, preferring forest.

4.12 Dominant Species

Dominant and subdominant species on both cover soils were similar in year 1 at SE dump (Table 2.30). LFH mineral soil mix was dominated by *Crepis tectorum*, a non-native common in disturbances. Subdominants were native (*Potentilla norvegica*, *Achillea millefolium*, *Chenopodium capitatum* (L.) Aschers. (strawberry blite)) and non-native (*Sonchus arvensis*). *Potentilla norvegica* and *Achillea millefolium* are native, early and early to late successional, respectively, and grow in forest and disturbed sites. The native *Chenopodium capitatum* grows mainly in disturbed places. On peat mineral soil mix, a native species, *Potentilla norvegica*, dominated with non-native subdominants (*Chenopodium album*, *Sonchus arvensis*, *Crepis tectorum*). LFH mineral soil mix had more native, forest type dominant and subdominant species than peat mineral soil mix in year 1.

In year 2 many of the same species appeared on both cover soils at SE dump (Table 2.31). Moss dominating LFH mineral soil mix was native; subdominant species were native (*Potentilla norvegica*, *Achillea millefolium*, *Carex* spp., *Geranium bicknellii* Britt. (Bicknell's geranium)) and non-native (*Crepis tectorum*). *Geranium bicknelli*, like *Potentilla norvegica*, is a native, early successional in boreal forests and disturbed areas. Moss and *Carex* cannot be specifically categorized, but most likely grow in forests rather than disturbed places. On peat mineral soil mix a non-native (*Chenopodium album*) dominated; subdominant species were native (moss, *Epilobium angustifolium*, *Potentilla norvegica*) and non-native (*Crepis tectorum*, *Sonchus arvensis*). *Epilobium angustifolium* is early successional, inhabiting forest and disturbed areas.

Dominant and subdominant species at SE dump on LFH mineral soil mix in differed in years 2 and 3; species on peat mineral soil mix were similar (Table 2.32). Four species occurred on both cover soils. The dominant on LFH mineral soil mix was native (*Rubus idaeus*), with native (*Achillea millefolium*, *Agrostis scabra*, *Poa palustris*, *Epilobium angustifolium* and *Aster ciliolatus*) and non-native (*Sonchus arvensis*) subdominants. *Epilobium angustifolium*, *Rubus idaeus*, *Agrostis scabra* and *Poa palustris* are native, early successionals of forest and disturbed areas. Early to late successional *Achillea millefolium* has the same habitat. Early to late successional *Aster ciliolatus* is native to boreal forest and uncommon in disturbed areas. Non-native *Sonchus arvensis* was dominant on peat mineral soil mix; subdominants were moss, *Crepis tectorum*, *Epilobium angustifolium*, *Rubus idaeus* and *Achillea millefolium*. This is a non-native and native mix of natural and disturbed habits, except moss is more common in forest. Peat mineral soil mix had greater shared species cover. *Sonchus arvensis* and *Epilobium angustifolium*; LFH mineral soil mix had more *Rubus idaeus* and *Achillea millefolium*. *Potentilla norvegica,* a biennial, was no longer dominant or subdominant. A formerly dominant annual *Crepis tectorum* and moss were not subdominant in year 3; both were subdominant on peat mineral soil mix.

In year 4 dominant species on both cover soils at SE dump were different but subdominants were the same (Table 2.33). LFH mineral soil mix was dominated by *Rubus idaeus*, peat mineral soil mix by moss, both native. *Rubus idaeus* is early successional and grows in natural and disturbed settings while moss is likely early to late successional in forest. Subdominants on both cover soils were *Epilobium angustifolium*, *Sonchus arvensis* and *Fragaria virginiana*; *Rubus* *idaeus* was subdominant on peat mineral soil mix. *Epilobium angustifolium* and *Fragaria virginiana* are native, early successionals in forest and disturbed environments. LFH mineral soil mix had greater *Rubus idaeus* cover, with *Epilobium angustifolium* and *Fragaria virginiana* similar on both cover soils; peat mineral soil mix had greater *Sonchus arvensis* cover. Dominance of moss on peat mineral soil mix was the main difference between cover soils.

Year 1 dominants and subdominants on both cover soils were competitive-ruderals, although one subdominant was a CR/CSR intermediate (Table 2.30). Year 2 dominants and subdominants on peat mineral soil mix were competitive-ruderals, competitives and moss (Table 2.31). Moss has strategies that could be defined as functional types, but a separate classification should be used, such as During's (1979) life strategy framework. Mosses are likely stress-tolerators, with pioneer types ruderal. Moss can immigrate but might have difficulty establishing (Campbell et al. 2003). On LFH mineral soil mix in year 2 there were three competitive-ruderals, one stress-tolerant-competitor and moss (also *Carex* which is impossible to characterize). Year 3 dominants and subdominants on both cover soils were stress-tolerant-competitive, competitive-ruderal, competitive and CR/CSR; only peat mineral soil mix had moss as subdominant (Table 2.32). LFH mineral soil mix was dominated by stress-tolerant-competitive species; peat mineral soil mix by competitive-ruderals. In year 4 both had stress-tolerant-competitive, competitive and competitive-ruderal dominants and subdominants (Table 2.33). Peat mineral soil mix was dominated by moss which was not dominant or subdominant on LFH mineral soil mix. Differentiating communities at SE dump based on C-S-R types was difficult. Temporal change from competitive-ruderal communities to a broader mix of species types is more interesting.

At Aurora in year 1 cover soils were dominated by *Epilobium angustifolium*, a native, early successional of disturbed places (Table 2.34). Subdominants on LFH mineral soil mix were native (*Lathyrus venosus*, *Rosa acicularis*, *Elymus innovatus*); peat mineral soil mix had native (*Agropyron trachycaulum*, *Urtica dioica*) and non-native (*Chenopodium album*) subdominants. *Rosa acicularis*, *Elymus innovatus* and *Lathyrus venosus* are early and late successionals in forest; *Rosa acicularis* is common in disturbed areas. *Chenopodium album* grows in disturbed areas and *Agropyron trachycaulum* and *Urtica dioica* are native early successionals in forest and disturbed areas. Peat mineral soil mix had early successionals; LFH mineral soil mix early to late successional subdominants.

In year 2 Aurora treatments were dominated by *Epilobium angustifolium* (Table 2.35). Subdominants on LFH mineral soil mix (*Elymus innovatus*, *Fragaria virginiana*, *Rosa acicularis*, *Geranium bicknelli*, *Lathyrus venosus*) and peat mineral soil mix (*Urtica dioica*, *Calamagrostis canadensis*, *Carex* spp., *Agropyron trachycaulum*), although different, were native, early successional forest species common after disturbance, except *Rosa acicularis*, *Lathyrus venosus* and *Elymus innovatus* (only on LFH mineral soil mix) associated with later stages and generally not common to disturbed places. *Carex* on peat mineral soil mix was likely a native, boreal forest species. Except for *Carex aquatilis* and *Carex bebbii* most boreal *Carex* species are atypical of disturbed areas. Subdominants were similar on LFH mineral soil mix; 10 cm on peat-sand had a few unique species.

In year 3 LFH mineral soil mix at Aurora continued to be dominated by *Epilobium angustifolium*; peat mineral soil mix was dominated by *Calamagrostis canadensis* (Table 2.36). Both are native early successionals. *Epilobium angustifolium* tends to natural and disturbed settings; *Calamagrostis canadensis* predominantly to forests. Subdominants on both covers are native except *Crepis tectorum*, typical of disturbed habitats. *Crepis tectorum* was subdominant on all treatments except 20 cm LFH mineral soil mix on sand. Other subdominants on LFH mineral soil mix (*Fragaria virginiana*, *Elymus innovatus*, *Rosa acicularis*) and peat mineral soil mix (*Epilobium angustifolium*, *Salix* spp., *Urtica dioica*, *Carex* spp.) were different, but haracterized as a mix of early and early to late successionals that grow in natural and disturbed places and some in natural forests exclusively.

In year 5 moss dominated three LFH mineral soil mix, treatments and co-dominated with *Fragaria virginiana* and *Epilobium angustifolium* on a fourth (10 cm on sand) (Table 2.37). Moss is more common in forest than disturbed environments and generally classified as early to late successional. Subdominants on LFH mineral soil mix (*Elymus innovatus*, *Fragaria virginiana*, *Epilobium angustifolium*, *Rosa acicularis*, *Carex* spp.) were similar to previous years. Peat mineral soil mix was dominated by a non-native (*Sonchus arvensis*) with *Koeleria macrantha*, *Aster ciliolatus* and *Carex* spp. subdominants, a complete turnover from year 3 except for *Carex*. *Koeleria macrantha*, *Aster* *ciliolatus* and *Carex* are native, early to late successionals in natural habitats. Subdominants on LFH mineral soil mix are common in natural and disturbed areas. *Crepis tectorum* as a subdominant was fleeting by year 5.

Year 5 minor differences occurred on LFH mineral soil mix at Aurora. *Rosa acicularis* was present at the sand site, but was not subdominant on 10 or 20 cm LFH mineral soil mix on sand; It was subdominant on LFH mineral soil mix on peat-sand. The 20 cm treatment on sand had no subdominant *Elymus innovatus*; it had similar covers of many species of other treatments, but occupied < 5 % of total cover on 20 cm LFH mineral soil mix on sand; total cover was higher.

Differentiating cover soils at Aurora based on C-S-R functional type was difficult. Year 1 was dominated by a competitive, with competitive, competitive ruderal or C/CSR subdominants (Table 2.34). Only peat mineral soil mix had an R/CR species. Years 2 and 3 functional types overlapped; three LFH mineral soil mix treatments (different both years) had a stress-tolerant-competitive subdominant; peat mineral soil mix did not (Tables 2.35, 2.36). In year 5, moss dominated three LFH mineral soil mix treatments, the fourth was co-dominated by a competitive, a stress-tolerant-competitive and moss; peat mineral soil mix was dominated by a competitive-ruderal (Table 2.37). Competitives, competitive-stress-tolerants, C/CSR species and competitive-ruderals subdominated LFH mineral soil mix. Subdominants on peat mineral soil mix were competitive and stress-tolerant.

W1 dump dominants and subdominants on 10 and 20 cm LFH mineral soil mix and 10 cm peat mineral soil mix were similar in year 1; all had *Epilobium angustifolium* (native) and *Sonchus arvensis* (non-native) (Table 2.38). The 20 cm peat mineral soil mix dominant was *Salix* (native), the co-dominant on 10 cm peat mineral soil mix. *Epilobium angustifolium* is early successional in natural and disturbed settings; *Salix* is early to late succcessional in natural forest. Subdominants on LFH mineral soil mix (*Rosa acicularis*, *Fragaria virginiana*, *Carex*) differed from those on peat mineral soil mix (*Equisetum arvense*, *Calamagrostis canadensis*, *Betula papyrifera*). They grow in natural forest. *Fragaria virginiana* and *Calamagrostis canadensis* are native, early successional; *Rosa acicularis*, *Carex*, *Equisetum arvense* and *Betula papyrifera* are native, early to late successional. *Fragaria virginiana*, *Rosa acicularis* and *Equisetum arvense* grow in natural forest and disturbed places.

In year 2 *Epilobium angustifolium* (native) dominated 10 cm LFH mineral soil mix and *Epilobium angustifolium* and *Sonchus arvensis* (non-native) co-dominated 20 cm at W1 dump (Table 2.39). *Crepis tectorum* (non-native) dominated peat mineral soil mix. LFH mineral soil mix had greater *Crepis tectorum* cover despite it being subdominant rather than dominant on this cover soil. *Sonchus arvensis* and *Fragaria virginiana* (native) on were subdominant on 10 cm LFH mineral soil mix and *Rubus idaeus* (native) on 20 cm. *Fragaria virginiana* and *Rubus idaeus* are early successionals found in natural and disturbed environments. *Sonchus arvensis* subdominated peat mineral soil mix with native *Epilobium angustifolium*, *Equisetum arvense*, *Potentilla norvegica*, *Agrostis scabra*, *Atriplex subspicata*, *Salix*, *Geranium bicknellii* and *Carex*. *Epilobium angustifolium*, *Potentilla norvegica*, *Agrostis scabra*, *Atriplex subspicata* and *Geranium bicknellii* are early successionals and *Equisetum arvense* early to late successional in natural and disturbed environments. *Salix* and *Carex* are early to late successional in forest.

In year 3 at W1 dump *Epilobium angustifolium* (native) dominated 10 and 20 cm LFH mineral soil mix and 20 cm peat mineral soil mix and co-dominated 10 cm peat mineral soil mix with *Crepis tectorum* (non-native) (Table 2.40), which also subdominated 20 cm peat mineral soil mix. Non-native *Sonchus arvensis* subdominated all treatments. Other subdominants did not overlap; both had early (*Fragaria virginiana*, *Rubus ideaus*, *Agrostis scabra*) and early to late successionals (moss, *Equisetum arvensis*, *Carex siccata* Dewey (hay sedge)) some of natural and disturbed habitats (*Fragaria virginiana*, *Rubus ideaus*, *Agrostis scabra*, *Equisetum arvensis*), others of natural (moss, *Carex siccata*).

In year 7 LFH mineral soil mix and peat mineral soil mix at W1 dump were dominated by native species (*Fragaria virginiana* and *Equisetum arvense*, respectively) (Table 2.41). There were a few non-native subdominants on peat mineral soil mix (*Taraxacum officinalis*, *Sonchus arvensis*). Most other species were the same except *Rubus idaeus* on 20 cm LFH mineral soil mix and *Salix* on 20 cm peat mineral soil mix. Species were mainly native, early successional , except *Equisetum arvense*, moss and *Salix*. *Equisetum arvense* is common in natural forest and disturbed places; moss and *Salix* are common in forests.

Competitive or competitive-ruderals dominated in year 1 at W1 dump (Table 2.38). Unlike at other sites, 20 cm peat mineral soil mix and 10 cm LFH mineral soil mix had a competitive-stress-tolerant subdominant species in year 1. In year 2, 10 cm and 20 cm LFH mineral soil mix and 20 cm peat mineral mix had competitive, competitive-ruderal and stress-tolerant-competitive dominants and subdominants (Table 2.39). The 10 cm peat mineral soil mix only had competitive and competitive-ruderal dominants and subdominants. Several subdominants on peat mineral soil mix were not classified. In year 3 the number of unclassified species prevented comparisons (Table 2.40). In year 4 all treatments continued to have competitive, competitive-ruderal and stress-tolerant-competitive species, and moss but only peat mineral soil mix had a R/CSR species (Table 2.41).

Year 13 MLSB, dominants were native on LFH mineral soil mix (*Fragaria virginiana*, *Rubus idaeus*) and non-native on peat mineral soil mix (*Sonchus arvensis*, *Lotus corniculatus*, *Taraxacum officinalis*) (Table 2.42). *Fragaria virginiana* and *Rubus idaeus* are early successionals common to natural and disturbed areas. Non-natives subdominated both cover soils (*Taraxacum officinalis*, *Medicago sativa*, *Lotus corniculatus*), with more natives on LFH mineral soil mix (*Rosa acicularis*, *Picea glauca*, *Elymus innovatus*, *Aster ciliolatus*, *Epilobium angustifolium*, *Galium boreale* L. (northern bedstraw), *Rubus idaeus*). Most grow in natural forest and disturbed areas, except *Picea glauca*, *Elymus innovatus* and *Aster ciliolatus* predominant in forest. *Fragaria virginiana*, *Epilobium angustifolium*, *Rubus idaeus*) were early successional; *Picea glauca*, *Aster ciliolatus*, *Rosa acicularis*, *Elymus innovatus*, *Galium boreale*) early to late.

Dominant species on LFH mineral soil mix at MLSB were stress-tolerant-competitives, while dominants on peat mineral soil mix were competitive-ruderals, R/CSR or S/CSR species (Table 2.42). Subdominant level trends in C-S-R functional types were difficult to discern due to classification issues.

5. DISCUSSION

5.1 Biologically Significant Numerical Differences

In many cases numerical differences between cover soils were noted despite not being statistically significant. In these cases the difference was large enough to have biological impacts on structure and function of the plant community. Important examples included woody plant density, species richness, native species richness and diversity at Cell 16 in year 13; native species richness at Cell 18 in year 13; and native species richness at Aurora in year 5. Some numerical differences in cover, such as at Cell 18 in year 13, could have had a biological impact on erosion protection, species interaction and ingress of new species. Other examples of note include native species cover at Aurora in year 5 and at W1 dump in year 7 and non-native cover at Aurora in year 5.

5.2 Plant Community Development

There are a number of ways in which LFH mineral soil mix developed greater woody plant densities, species richness, native species richness, total cover and native cover and lower non-native cover than peat mineral soil mix. These factors explain cover soil differences in growth form assemblage, species composition, dominant species and types of species (successional stages, habitat types, CSR strategies). The first factor is the propagule bank of donor material and how it is transferred to the receiver site. Species richness in the propagule bank can influence species richness of emergent vegetation and number of propagules of each species will impact density and canopy cover of each species and of various types of species. The second factor is condition of the cover soils and how its propagules respond to those conditions. Types of species that arrive at the receiver site through wind and animal dispersal respond to the soil conditions. A third factor is biotic interactions that occur among species that establish. These factors also drive plant community development in early successional sites, post fire or post logging, although reclamation sites cannot be expected to follow development patterns observed after these disturbances.

Differences in cover soil propagule banks may be the most obvious factor affecting plant community development, but was not necessarily most decisive for some plant groups. Donor upland surface soil for W1 dump had significantly more grass, sedge, rush, forb and native propagules in the upper 10 cm than donor peat, but materials did not differ significantly in number of woody plant propagules (Mackenzie 2006, Mackenzie and Naeth 2010). Total and native emergents were significantly higher in the upper 10 cm of donor upland surface soil than donor peat. Large losses of propagules occurred during transfer of salvaged material to the W1 dump receiver site (Mackenzie 2006, Mackenzie and Naeth 2010). Number and type of emergents from propagule banks from cover soils at the receiver site were similar, and more related to application depth than cover soil. Woody plants, pteridophytes and non-native plants had lowest emergents. Differences in propagule bank size at the donor sites did not translate into differences at the receiver site, although the propagule bank of LFH mineral soil mix at the receiver site had almost double the number of species of peat mineral soil mix. Large propagules losses were also observed on LFH mineral soil mix at Aurora (Mackenzie 2012a). Propagule densities in propagule banks from receiver sites were low, with cover soils having similar numbers of grass and woody propagules; LFH mineral soil mix likely had more forb propagules. Propagule bank density may have been underestimated due to difficulties in sampling vegetative propagules with cylindrical sampling tools. Despite these losses, LFH mineral soil mix at the receiver site had higher propagule bank species richness than peat mineral soil mix. No information was available about propagule banks of SE dump or MLSB donor materials but through salvage and placement operations similar losses likely occurred, resulting in both cover soils having propagule banks that are more similar to each other than the propagule banks of the original donor soils were, at least in growth form assemblage.

Large propagule losses have been observed in post mining propagule bank transfer studies in Australia. Koch et al. (1996) reported losses of propagules during reclamation; after clearing 74 % of the seeds remained, after stripping and stockpiling 31 % remained, after 10 months in the stockpile 13 % remained and after placement and ripping 16 % remained. Some factors that explain losses in propagules during these phases, and potentially the difference in numbers of propagules in LFH mineral soil mix and peat mineral soil mix, include material mixing, root wounding and stockpiling. Stripping, stockpiling and placement can dilute propagules, as propagule rich upper layers are mixed with propagule poor soil from lower in the salvage profile, especially with deep salvage (Rokich et al. 2000, Mackenzie 2006, Mackenzie and Naeth 2010, Mackenzie 2012a).

Viable propagules are buried at depths from which they cannot emerge. Peat mineral soil mix is salvaged by over stripping peat deposits to include 25 to 40 % of the underlying mineral material from areas where there is a minimum of 60 cm of peat (AMEC 2007). Depth of salvage is close to 1 m which will almost certainly result in propagule dilution. Depth of salvage for upland surface soil is generally much shallower, to maximum depths of 30 cm.

Root wounding could have occurred during all reclamation phases. It occurs in forestry operations due to large machinery traffic and can reduce living root mass, carbohydrate reserves and suckering performance in *Populus tremuloides* (Renkema et al. 2009). Only vegetative propagules would be affected, making treatments with more vegetative propagules more sensitive to root wounding effects than treatments with more seeds. Donor peat material for W1 dump had more vegetative propagules than donor LFH mineral soil mix (35 vs 10 % of the propagule bank, respectively) (Mackenzie 2006). In contrast, donor LFH mineral soil mix at Aurora had more emergents from vegetative propagules (71 %) than from seeds in the propagule bank (Mackenzie 2012a). Other boreal forest studies found upland surface soil propagule banks composed of 15 to 35 % vegetative propagules and 65 to 85 % seeds (Archibold 1979, Whittle et al. 1998).

Stockpiling can lead to significant losses in viability within 8 months (Mackenzie 2012a). At most of our sites donor materials were stockpiled for less than 6 months, and donor LFH and peat materials were generally stockpiled for similar times (up to 3 months difference between the two cover soils). However, stockpiling times for peat mineral soil mix was not well documented at Aurora or MLSB and may have been significantly longer than the LFH mineral soil mix.

Since propagule banks respond to soil conditions it can be difficult to determine which is more important. Both could be driving differences seen in cover soils. Both cover soils could have had the same number of propagules but LFH mineral soil mix was more favourable for their germination and growth; both covers could have had similar conditions and LFH mineral soil mix had more propagules; or perhaps it was a combination of both. Covers may have had different types of propagules. Number of propagules and soil conditions could be equivalent on both and LFH mineral soil mix may have performed better because species in the propagule bank were better adapted to conditions, or species in peat mineral soil mix were more poorly adapted. For example, species in peat mineral soil mix may not have been tolerant of dry conditions at upland receiver sites.

Research suggests LFH mineral soil mix provides a more suitable environment for plant germination and growth, particularly available nutrients and microbial associations. In year 2 at W1 dump LFH mineral soil mix had higher soluble potassium and available phosphorus than peat mineral soil mix (Mackenzie and Naeth 2010). At Aurora in year 3 LFH mineral soil mix had higher available phosphorus and extractable potassium than peat mineral soil mix (Mackenzie 2012a). At SE dump in years 1 and 2 LFH mineral soil mix had higher available phosphorus and potassium (Brown 2010). Peat mineral soil mix had higher total carbon, total nitrogen and cation exchange capacity, although in some studies values on both covers were similar (AMEC 2007, Mackenzie and Naeth 2010, Mackenzie and Quideau 2012, Pinno et al. 2012, Hahn 2012, Mackenzie 2012, Brown 2010). Peat mineral soil mix can have higher pH and electrical conductivity. In some cases differences between cover soils can result in a good rating for LFH mineral soil mix according to soil quality criteria (Alberta Soils Advisory Committee 1987) and a fair rating for peat mineral soil mix (Mackenzie 2012a). Microbial communities can differ on cover soils (Mackenzie and Quideau 2012). In the longer term, 6 to 10 years after reclamation, microbial community composition on LFH mineral soil mix was becoming more similar to natural reference stands than on peat mineral soil mix (Hahn 2012).

Of the vegetation parameters, total cover is likely most related to soil conditions. Increased organic matter led to increased plant growth in forest revegetation (Claassen and Zasoski 1993, Skrindo and Halvorsen 2008). This was observed at Aurora with higher cover on deeper placements in year 5. Deep and shallow applications had similar total carbon and nitrogen, cation exchange capacity and available nutrients in year 3 (Mackenzie 2012a) but different water holding capacities (not measured) may have been a factor. Application depth effect on total cover in years 1 to 3 at W1 dump was difficult to detect in year 7 even between cover soils. Total cover still differed between cover soils in the longer term at other sites, which may reflect soil fertility differences. Total cover may reflect species richness as each additional species adds to the total. This effect likely decreases with time as space becomes more restricted and is confounded by some species occupying more space than others, and cover can be higher with a few of these species relative to a community with many low cover species.

Although it appears LFH mineral soil mix was a better growing medium, there is evidence to suggest peat mineral soil mix can be an equally good. Over time vegetation on both covers at some sites is becoming more similar (for example in species richness, native species richness, woody plant density, total cover) which is likely due to species spreading from LFH mineral soil mix onto peat mineral soil mix. This suggests peat mineral soil mix is an equally good medium for plant growth at those sites but did not have the same number and type of propagules that LFH mineral soil mix had in earlier years. Skrindo and Halvorsen (2008) found propagule bank content was more important than soil nutrient balance in determining species composition in a roadside reclamation experiment in boreal Sweden, although they noted this only happens as long as there is no deficiency of essential nutrients. Topsoil and subsoil treatments had small differences in organic matter and texture but different species after 3 years.

Cover soils were not becoming more similar in non-native cover. Based on the assumption that total cover may reflect soil quality, native and non-native species should respond in the same way to cover soil they grow on, but this is not the case in the longer term. In the final year of assessment treatments with greater native cover (LFH mineral soil mix) did not have greater non-native cover. Non-native cover remained low or was decreasing over time on LFH mineral soil mix, but was increasing over time on peat mineral soil mix. At Cell 16 peat mineral soil mix had more non-native cover than native cover in year 13. At Cell 18 native and non-native covers were the same on peat mineral soil mix. If trends in native and non-native cover are not based on fertility, there must be an alternative explanation for different trends observed on different cover soils. The answer may lie in biotic interactions that occur once species start to become established.

Better access to native propagules in early stages set LFH mineral soil mix communities on a different trajectory than those on peat mineral soil mix. Lower native species cover and corresponding lower competition on peat mineral soil mix early on likely allowed more non-natives to establish, gaining a foothold that may be difficult to eradicate. On LFH mineral soil mix, trends must be examined in the context of biotic interactions and strategies of native vs non-native species. Non-native species may be decreasing due to competition. Several non-native species are annuals and biennials (*Chenopodium album*, *Crepis tectorum*) and are likely reproducing by seed rather than vegetatively. With greater native cover on LFH mineral soil mix, when these seeds land they may have difficulty establishing with competing native species. Native plants could have a competitive advantage if they are reproducing vegetatively because new shoots would have support of the parent plant, which seedlings establishing from seed would not (Crawley and May 1987). Native species may have an advantage on LFH mineral soil mix due to interactions with microorganisms and soil conditions.

Growth form assemblages and plant community differences on cover soils can be similarly explained. Each species forming the plant community has different strategies that can affect the ability of other species to co-exist in that community. Competition and shading are some ways species interact that can affect species richness. Since bare mineral soil is the preferred seed bed for many species (Roberts 2004, Kemball et al. 2005) litter increases over time related to increased canopy cover result in less space for new species. The initial floristics model suggests the first species to arrive and establish direct, to some degree, future trajectories on a site (Egler 1954, Weigleb and Felinks 2001a). In boreal forests greater changes in species composition can be expected in the first decades of recovery from a disturbance after which changes are generally only in the relative abundances of species (De Grandpre et al. 1993 cited in Hart and Chen 2006).

Thus in the short term LFH mineral soil mix likely had more species because it had more propagules suited to conditions at the receiver sites. In the longer term these species moved onto peat mineral soil mix, indicating conditions there are also suitable for these species, which led to fewer significant differences. With the propagule constraint practically gone, the main reason some peat mineral soil mix treatments had significantly fewer species or less cover or different species compositions, is soil conditions and biotic interactions. The same factors may explain why some LFH mineral soil mix treatments have the most species.

5.3 Differences Among LFH Mineral Soil Mix Treatments

Differences at Aurora on LFH mineral soil mix, including biologically significant numerical differences, were driven by interactions of application depth, substrate type and LFH donor material. Woody plant densities likely differed due to the latter two factors while growth forms differed due to application depth. In year 5, 20 cm LFH mineral soil mix on sand had more woody plants than 10 and 20 cm on peat-sand. In contrast, both 20 cm treatments had higher forb and moss cover than 10 cm. The 20 cm treatments were more similar to each other in growth form assemblages than to 10 cm on the same substrate; similarly for 10 cm.

There were no significant or numerical differences on LFH mineral soil mix due to application depth at W1 dump or season of placement or stockpiling at Cell 18. Differences between Cells 16 and 18 were likely due to substrate. Cell 18 LFH mineral soil mix was placed on peat mineral soil mix while at Cell 16 it was placed on secondary material which would have different organic matter and nutrients. Cell 18 LFH mineral soil mix had higher woody plant density, total cover and native cover and a different assemblage of growth forms than Cell 16.

5.4 Consistency Of Effects

Many factors make site conditions different, which may impact developing plant communities and responses to cover soils. Likely as a result, LFH mineral soil mix was not significantly different from peat mineral soil mix for the same parameters in the same years at all sites. Every site had at least two significantly different parameters between cover soils; some had significant differences for five parameters. In the final assessment year, most significant differences were at Aurora and SE dump, with fewer at Cell 18 and least at W1 dump. Overall there were enough significant differences to show that the positive effect of LFH mineral soil mix is consistent under different conditions. External factors affecting sites help explain variation in patterns of significant differences between covers.

5.4.1 Rainfall

Growing season rainfall was not consistent across sites, although all were drier than normal during the study. Thus plant communities developed in drier than normal conditions, which could affect which species survived early on and which species came to dominate. Propagules from peat mineral soil mix were likely more affected by dry conditions than those in LFH mineral soil mix. Had it been wetter more wetland species might have appeared on peat mineral soil mix.

Site data were rarely available for all years vegetation was assessed. Vegetation assessments at W1 dump took place in relatively wet years compared to the overall data set (except 2004 with no data). More significant differences might have occured in drier years. All study years at Aurora were dry, which may have influenced the large number of significant differences. At SE dump years 3 and 4 were very dry, potentially accentuating cover soil differences; there was no data for years 1 and 2. With no year 13 data at MLSB, inferences cannot be drawn.

5.4.2 Water regime modifiers: slope, aspect and substrate

Slope and aspect modify soil water on the landscape; sites with similar rainfall but different slopes and aspects can have different soil water regimes. Cell 16 is almost level; SE dump (2.5 to 10 %) and the peat-sand site (5 to 10 %) had the shallowest slopes, and the sand site (10 to 20 %) had steepest. Slopes at W1 dump (6 to 16 %) and Cell 18 (8 to 14 %) were intermediate. Based on slope the sand site would likely be driest were it not for its north-facing aspect, known to be less dry than south-facing aspects. Aurora and Cell 18 plots were on-north facing slopes, while SE dump and W1 dump plots faced ESE and SE, respectively.

Substrate upon which cover soils were placed affects water holding capacity and thus water regime. Coarse texture at the sand site coupled with steeper slopes likely makes it driest despite its north facing aspect. LFH mineral soil mix was placed over B and C horizon material at SE dump and secondary material at W1 dump, both fine textured. Despite their substrate, the SE aspect likely makes these two sites next driest. The peat-sand site has a coarse textured, peaty substrate, which combined with its north facing shallow slopes likely make it less dry than SE dump and W1 dump. Cell 18 substrates are peat mineral soil mix or secondary, or both, making them mesic with their north facing, moderate slopes.

5.4.3 Distance to natural forest

Distance of the reclaimed site to natural forest affects seed travel and wildlife use. Wildlife can bring new propagules onto the site. Wildlife were observed at SE dump during assessments, and moose and deer scat was found at Cell 18. There was no evidence of wildlife at Aurora or W1 dump. However, as wildlife was not the focus of data collection this is not an indication they were absent.

Exact distances to natural forests were not measured, but based on maps research sites are similar distances from undisturbed forest. No site was less than 1 km from patches of undisturbed forest. This factor is likely unimportant in driving differences between sites in significant differences between cover soils.

5.4.4 Fertilizer and nitrogen deposition

SE dump was most heavily fertilized. Peat mineral soil mix was fertilized in year 1 at MLSB but LFH mineral soil mix was not (McMillan et al. 2007). W1 dump and Aurora were not fertilized. Due to their location they likely received different rates of nitrogen deposition. In the oil sands region nitrogen pollution originates from bitumen extraction and upgrading facilities and other industrial activity including exhaust from trucks and other machinery (Bytnerowicz et al. 2010). Aurora sites are furthest from active processing; the others are within similarly distances. Other factors such as precipitation and canopy cover should be considered before determining Aurora had lowest nitrogen deposition (Hemsley 2012).

Fertilizer, including nitrogen deposition, can affect canopy cover, species richness and species composition, favouring certain species (Rowe et al. 2006, Moreno-Penarando et al. 2004, Walker and del Moral 2008). SE dump, the most heavily fertilized, had highest total, native and non-native cover early on, but longer term the sites were becoming more similar for these parameters. There were still several significant differences between cover soils at SE dump despite its high fertilizer load. There was no correlation between fertilizer and significant differences between cover soils. Cell 16 and 18 are a special case because peat mineral soil mix was fertilized but LFH mineral soil mix was not. This could have played an early significant role but is unlikely to be driving differences in year 13.

5.4.5 Source of LFH and stockpiling effects

The type of forest community from which LFH mineral soil mix was salvaged can be critical in determining species composition of the plant community that developed at the receiver site, assuming propagules survived the journey. Stockpiling for greater than one year can essentially destroy all of the live propagules present in the LFH mineral soil mix (Mackenzie 2012a).

LFH mineral soil mix at Aurora sand and peat-sand sites was salvaged from *Pinus banksiana* and *Pinus banksiana-Populus tremuloides* mixedwood stands, respectively (Mackenzie 2012a). LFH mineral soil mix at SE dump originated from a similar stand with *Populus tremuloides*, *Picea glauca* and *Pinus banksiana* and understory species associated with b and d ecosites (Brown 2010). LFH mineral soil mix at W1 dump was salvaged from a donor site with *Populus* *tremuloides,* a few *Picea glauca* and associated understory species (Mackenzie 2006). LFH mineral soil mix for MLSB was salvaged from a dry upland *Populus tremuloides* community which was likely similar to the donor site for W1 dump (Lanoue and Qualizza 2000). Salvage depth was shallower than for other LFH mineral soil mix treatments salvaged at 20 to 25 cm. Despite donor material differences significant differences were found at all sites, suggesting LFH mineral soil mix from different ecosites worked well in reclamation. Vegetation on peat mineral soil mix donor sites was only available for W1 dump. It was dominated by *Salix* sp., *Ledum groenlandicum*, *Oxycoccus microcarpus*, *Vaccinium vitis-idaea*, *Carex* sp. and *Calamagrostis canadensis* (Mackenzie 2006). These species, if found at all, were in much smaller quantities on peat mineral soil mix, than LFH donor site species were on LFH mineral soil mix, suggesting species composition of donor sites is not a key determinant of composition in the reclaimed landscape for peat mineral soil mix. Its propagules do not flourish at upland receiver sites.

LFH mineral soil mix stockpiling varied from a few days for Cell 18 summer placement to 6 months at Aurora (Lanoue and Qualizza 2000, Mackenzie 2012a). LFH mineral soil mix was stockpiled 3 months prior to placement at SE dump, 3 to 4 months at W1 dump and 5 months for Cell 16 and 18 winter placement (Lanoue and Qualizza 2000, Mackenzie 2006, Brown 2010). Stockpiling of peat mineral soil mix was not as well documented. At SE dump peat mineral soil mix was directly applied after salvaging and at W1 dump it was stockpiled 3 to 4 months in winter (Mackenzie 2006, Brown 2010). No stockpiling durations were long enough to severely affect propagule banks, although some losses in viability may have occurred at Aurora due to 6 months stockpiling. If cover soils were stockpiled for the same amount of time, stockpiling duration is likely not driving cover soil differences. This was only the case at W1 dump. SE dump peat mineral soil mix was not stockpiled while LFH mineral soil mix was. At Aurora and MLSB there was no information on peat mineral soil mix stockpiling, but it is likely donor peat material was stockpiled longer than upland surface soil.

5.4.6 Tree planting

Trees were planted at W1 dump and Cells 16 and 18 but not SE dump or Aurora. Tree planting has obvious effects on woody plant density and development of plant communities, but because both cover soils were treated the same way it is unlikely to be the cause of significant differences between LFH mineral soil mix and peat mineral soil mix. However, tree planting could have equalized vegetation developing on both cover soils, making differences harder to detect.

5.4.7 Experimental unit size

Experimental unit size varied with site, with W1 dump having the largest (25 by 150 m) and SE dump the smallest (10 by 30 m). Experimental unit size at SE dump may have been a factor in the similar species composition on LFH mineral soil mix and peat mineral soil mix. Small plots likely resulted in intermixing between plots, while larger plots at other sites may have reduced intermixing.

6. CONCLUSIONS

Results support preferential use of LFH mineral soil mix as a cover soil instead of peat mineral soil mix in oil sands reclamation. Significant differences in vegetation occurred at four sites, 4 to 13 years of age; with the benefits of LFH mineral soil mix repeated at multiple sites.

- Woody plant density, species richness, native species richness, total cover and native species cover were higher on LFH mineral soil mix than peat mineral soil mix at one or more sites.
- Non-native species cover was lower on LFH mineral soil mix than peat mineral soil mix at one or more sites.
- Species composition and assemblage of growth forms differed with cover soil at two or more sites. Dominant and subdominant species on LFH mineral soil mix were always native while on peat mineral soil mix they were often non-native. Forbs were the dominant growth form on peat mineral soil mix at all sites while LFH mineral soil mix was dominated by forbs at some sites, or co-dominated by forbs and moss or forbs and shrubs at other sites. Shrub cover was generally greater on LFH mineral soil mix than peat mineral soil mix.
- The interaction of application depth, substrate type and donor LFH material at Aurora had significant impacts on vegetation after 5 years. A 10 cm application of LFH mineral soil mix from a *Pinus banksiana* and *Populus tremuloides* mixedwood forest on the sand substrate was least effective. There was no application depth effect (10 vs 20 cm) on vegetation after 7

years at W1 dump and there was no season of placement or short term stockpiling effect on vegetation after 13 years at Cell 18.

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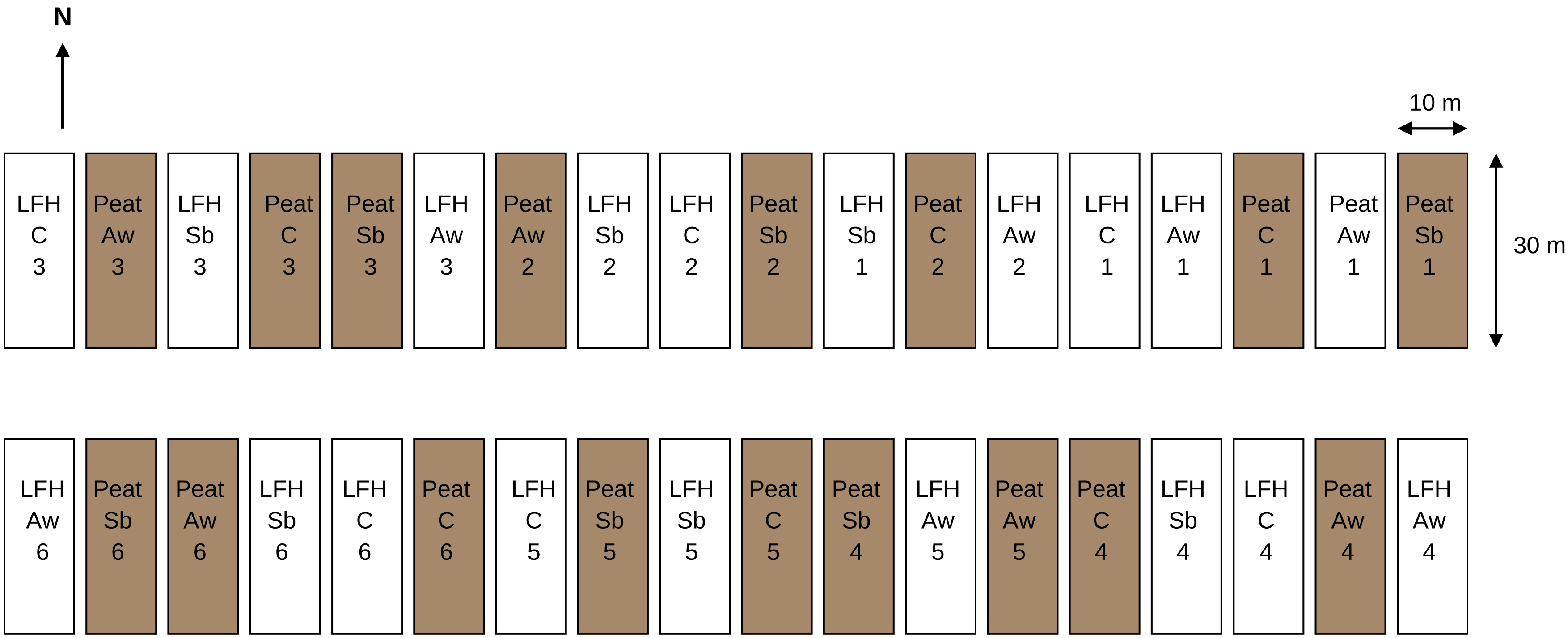

Figure 2.1. Research plot layout at SE dump. White plots have LFH mineral soil mix; brown plots have peat mineral soil mix. Woody debris type is designated as Sb = Picea mariana, Aw = Populus tremuloides, C = control with no woody debris. Numbers denote treatment replicates (six in total).

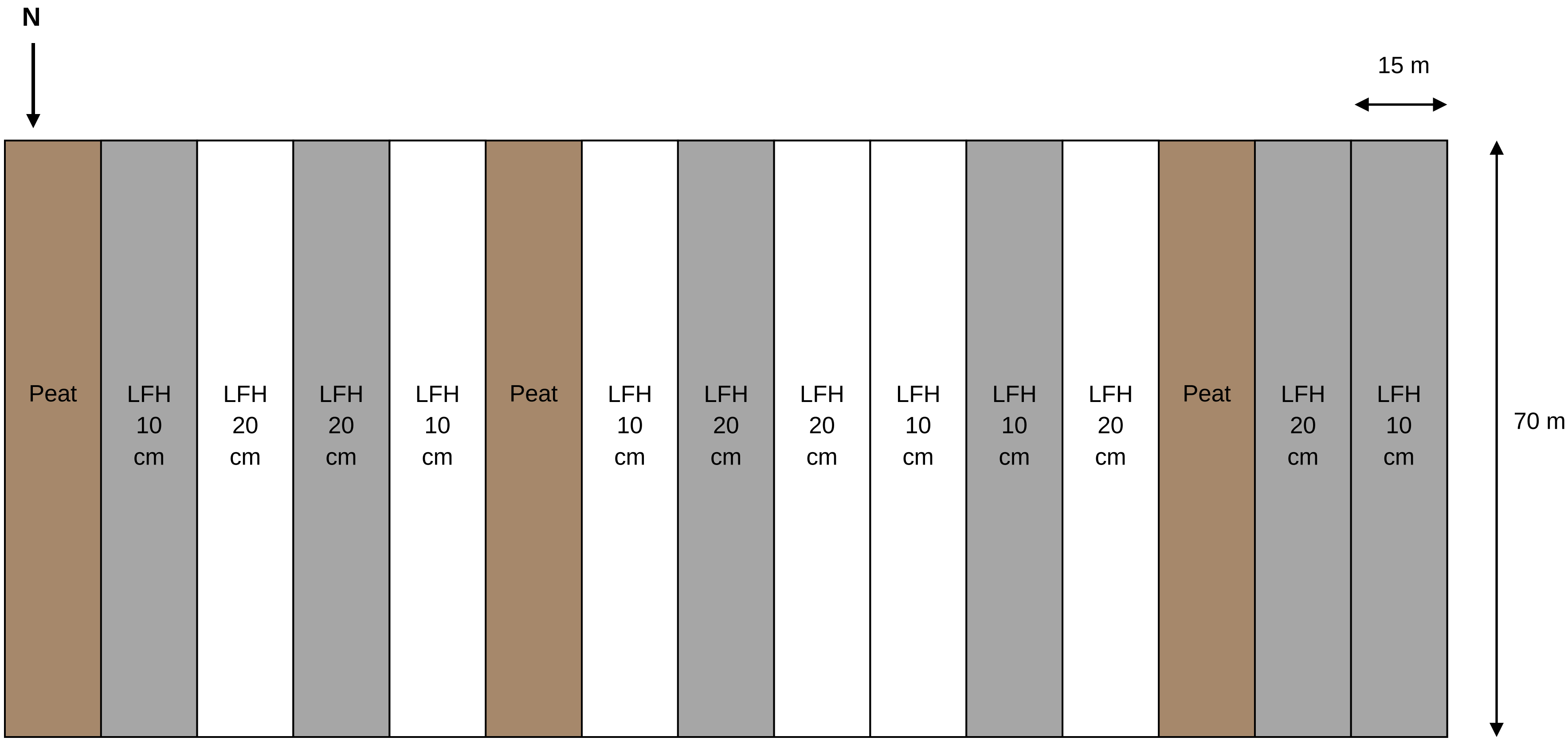

Figure 2.2. Research plot layout at Aurora on peat-sand substrate. Gray plots are LFH mineral soil mix salvaged to 25 cm; white plots are LFH mineral soil mix salvaged to 10 cm; brown plots are peat mineral soil mix (50 % fen peat, 50 % sand). Depths noted in the figure are application depths; there are three replicates of each salvage depth – application depth combination for LFH mineral soil mix and three peat mineral soil mix controls.

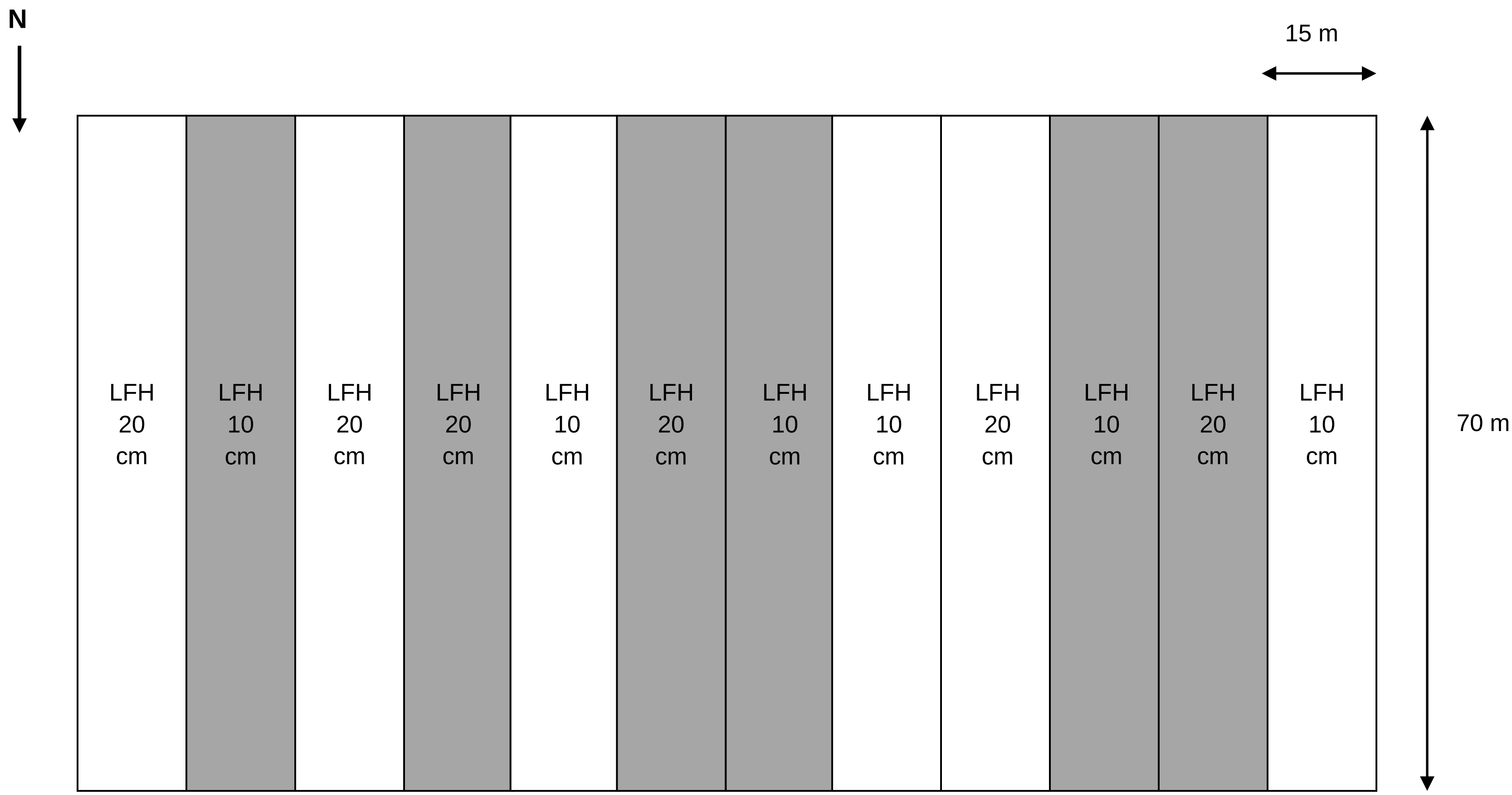

Figure 2.3. Research plot layout at Aurora on sand substrate. Gray plots are LFH mineral soil mix salvaged to 25 cm; white plots are LFH mineral soil mix salvaged to 10 cm. Depths noted in the figure are application depths; there are three replicates of each salvage depth – application depth combination.

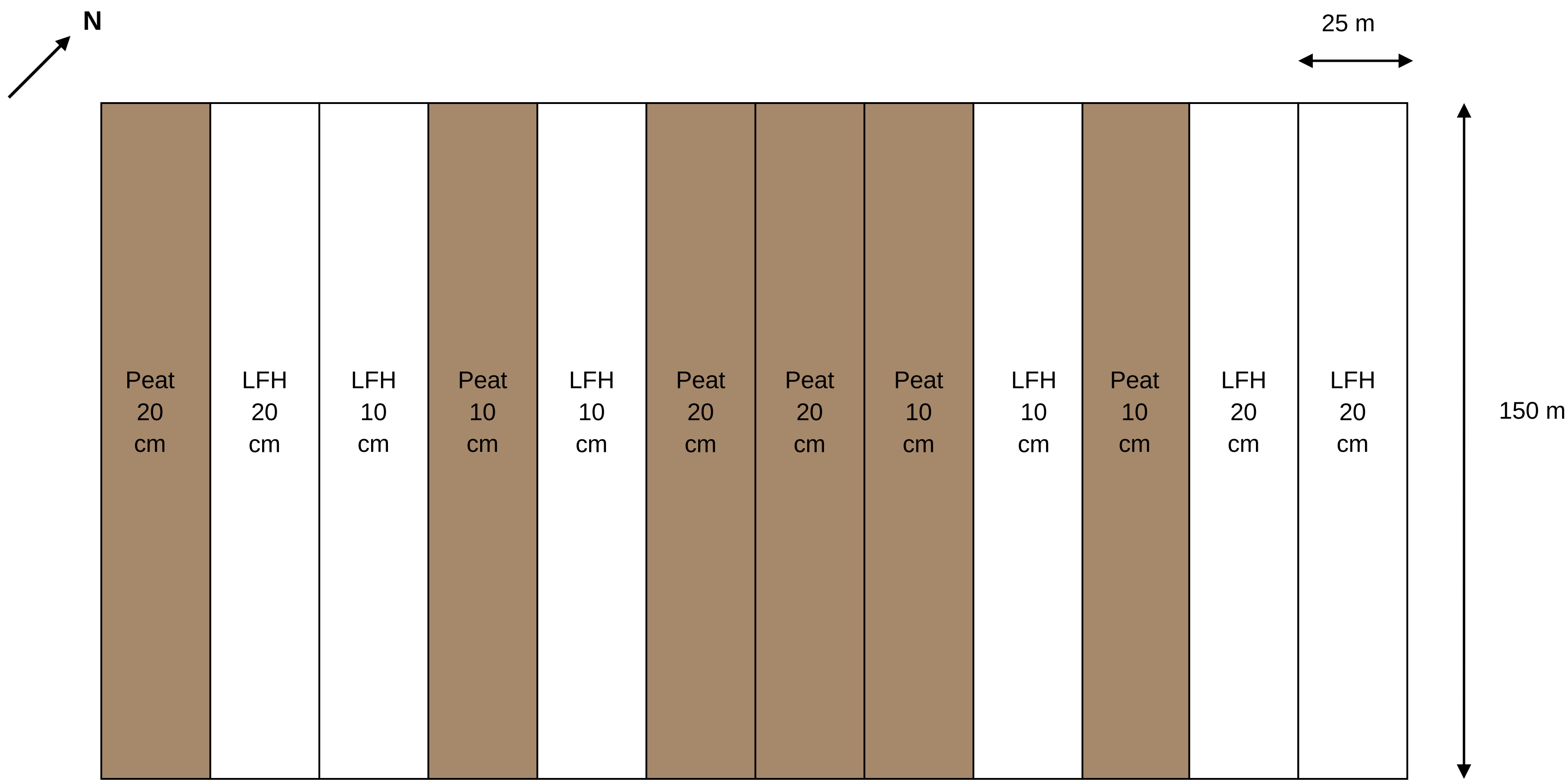

Figure 2.4. Research plot layout at W1 dump. White plots are LFH mineral soil mix applied at depths of 10 and 20 cm, brown plots are peat mineral soil mix applied at depths of 10 and 20 cm. There are three replicates of each cover soil – application depth combination.

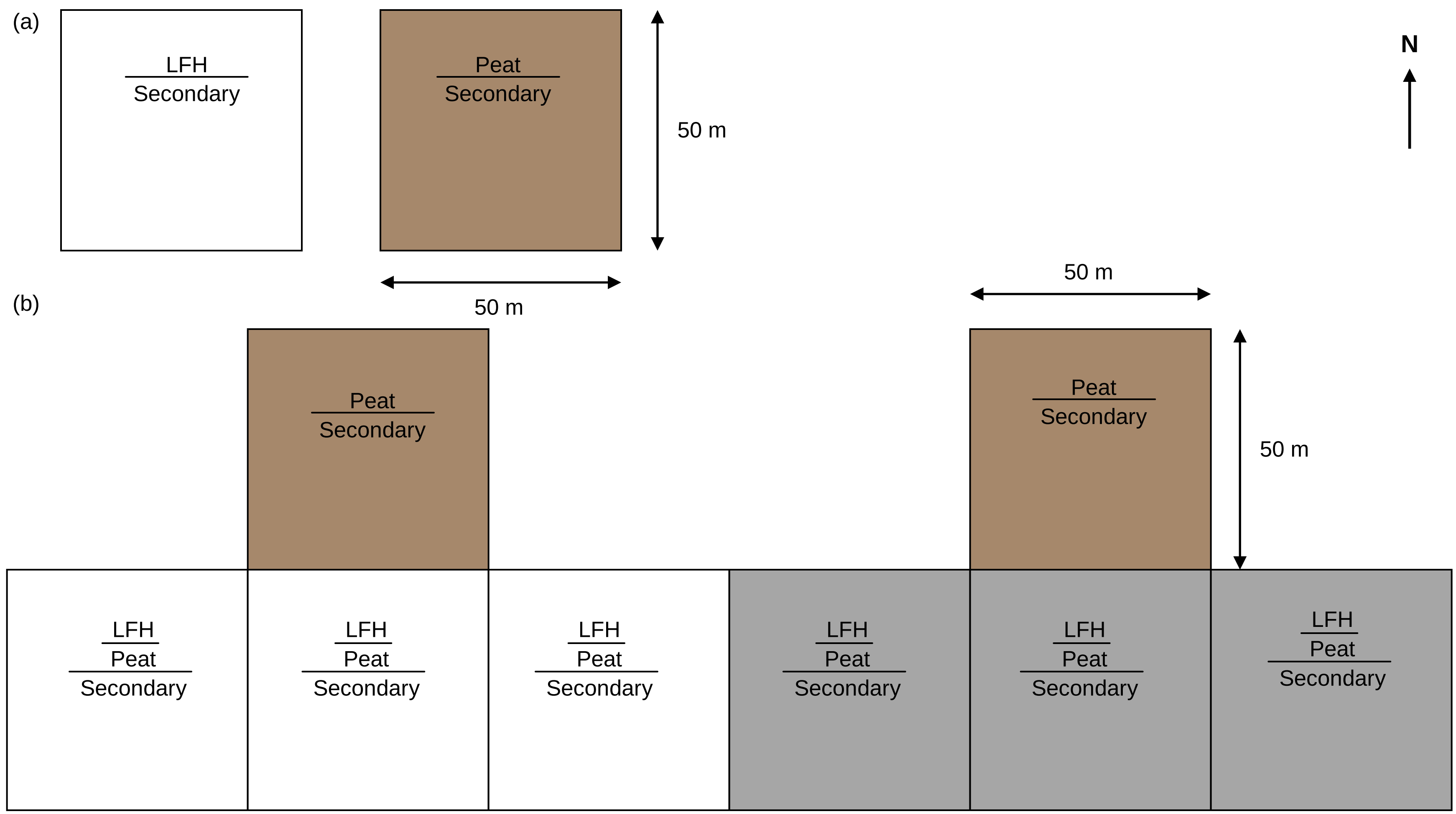

Figure 2.5. Research plot layout at Mildred Lake Settling Basin; (a) Cell 16, (b) Cell 18. White plots are LFH mineral soil mix with winter placement; gray plots are LFH mineral soil mix with summer placement; brown plots are peat mineral soil mix.

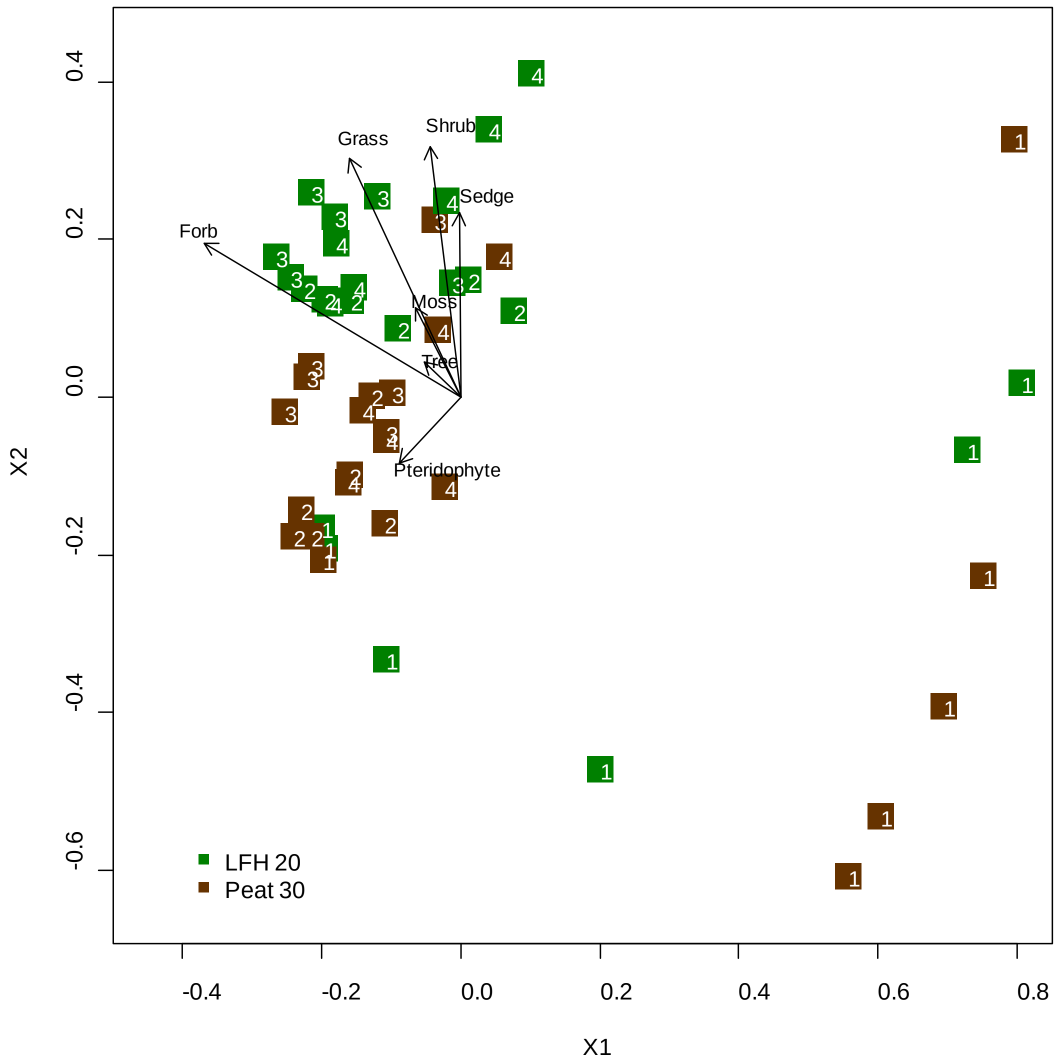

Figure 2.6. NMDS ordination (X1 vs X2) of growth form groups in years 1, 2, 3 and 4 after reclamation at SE dump.

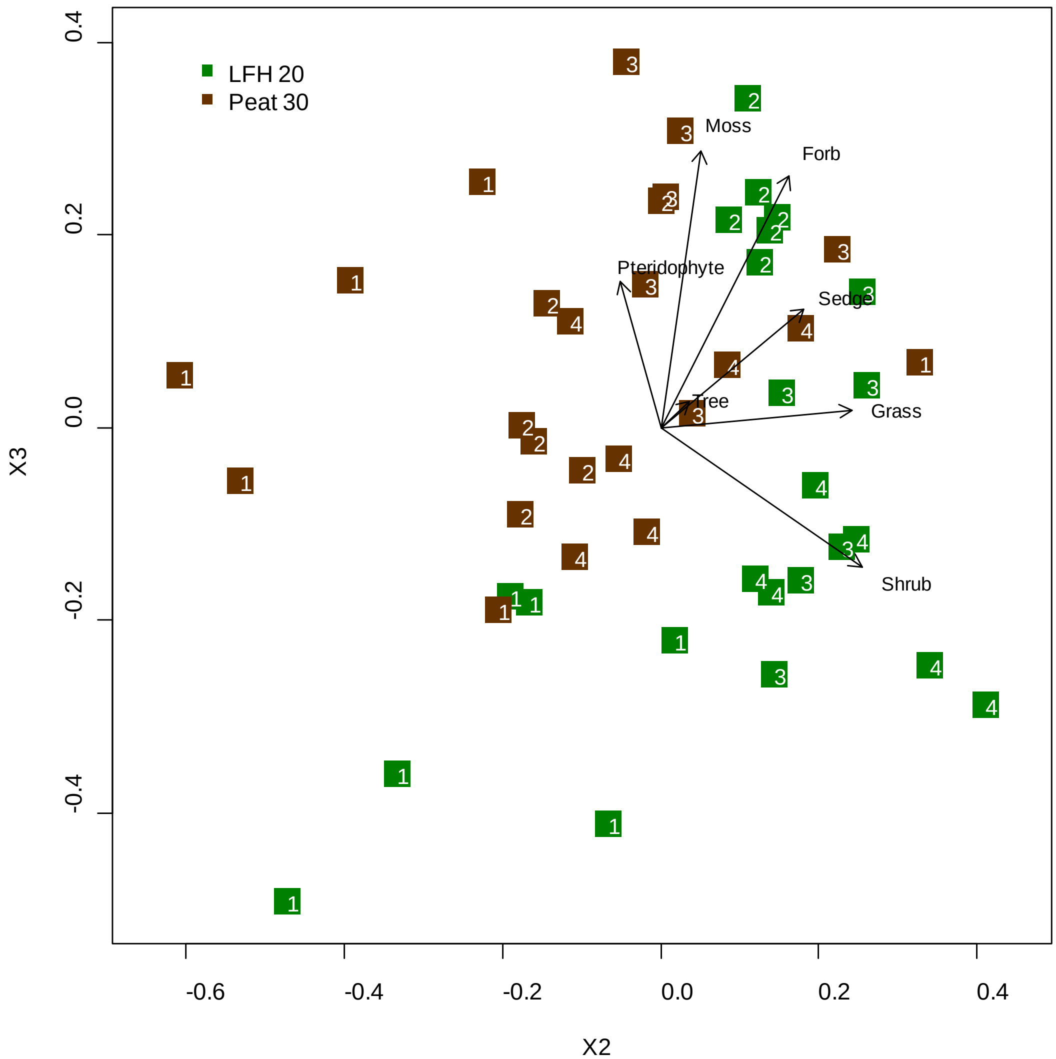

Figure 2.7 NMDS ordination (X2 vs X3) of growth form groups in years 1, 2, 3 and 4 after reclamation at SE dump.

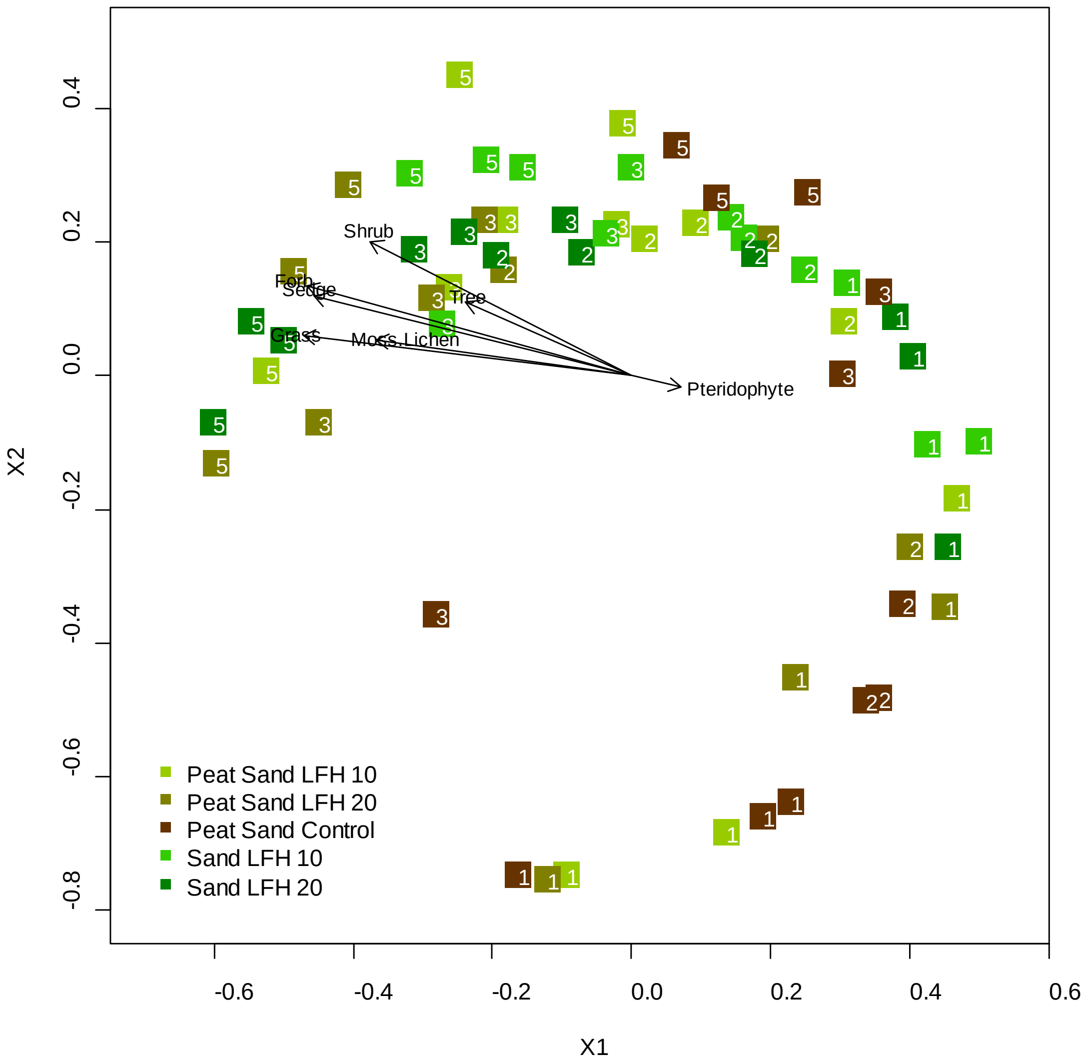

Figure 2.8 NMDS ordination of growth form groups in years 1, 2, 3 and 5 after reclamation at Aurora.

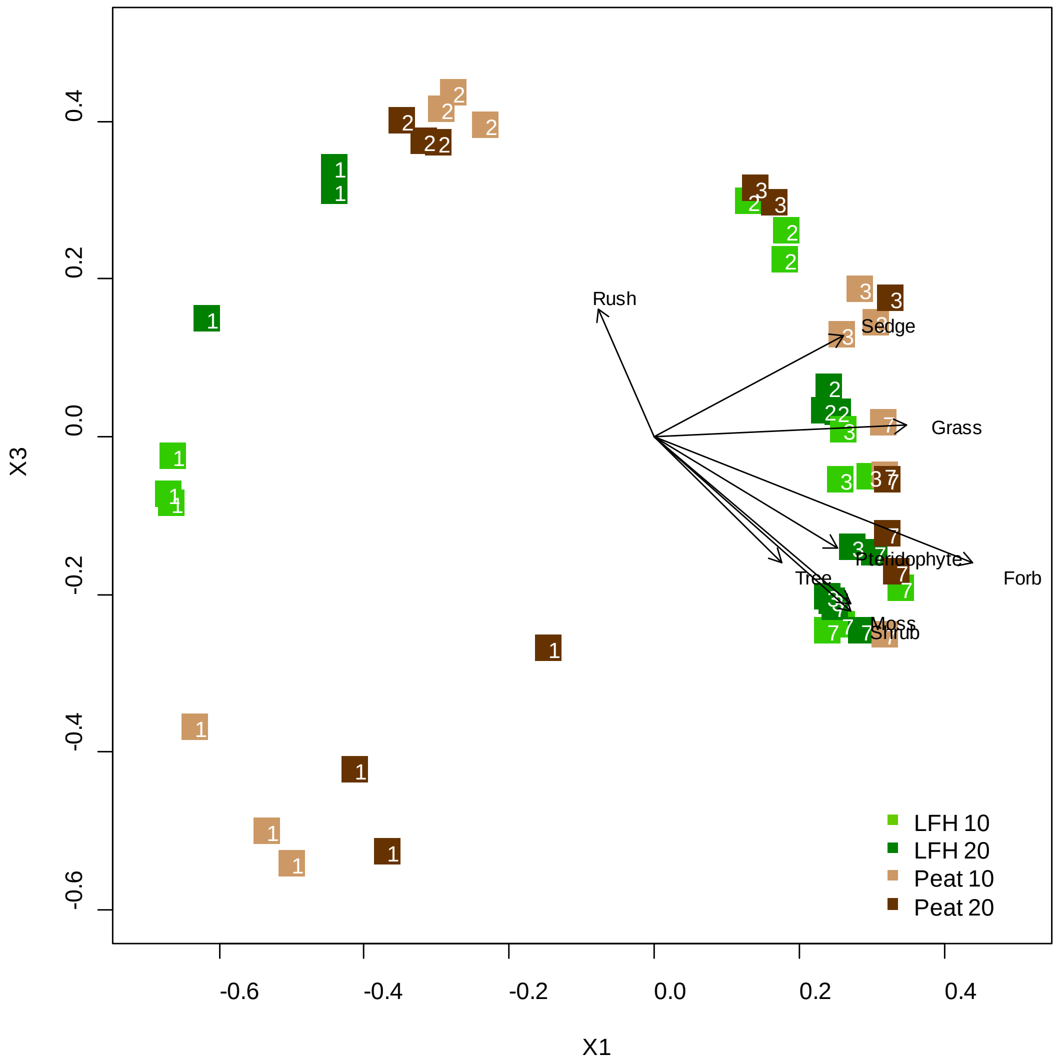

Figure 2.9 NMDS ordination (X1 vs X3) of growth form groups in years 1, 2, 3 and 7 after reclamation at W1 dump.

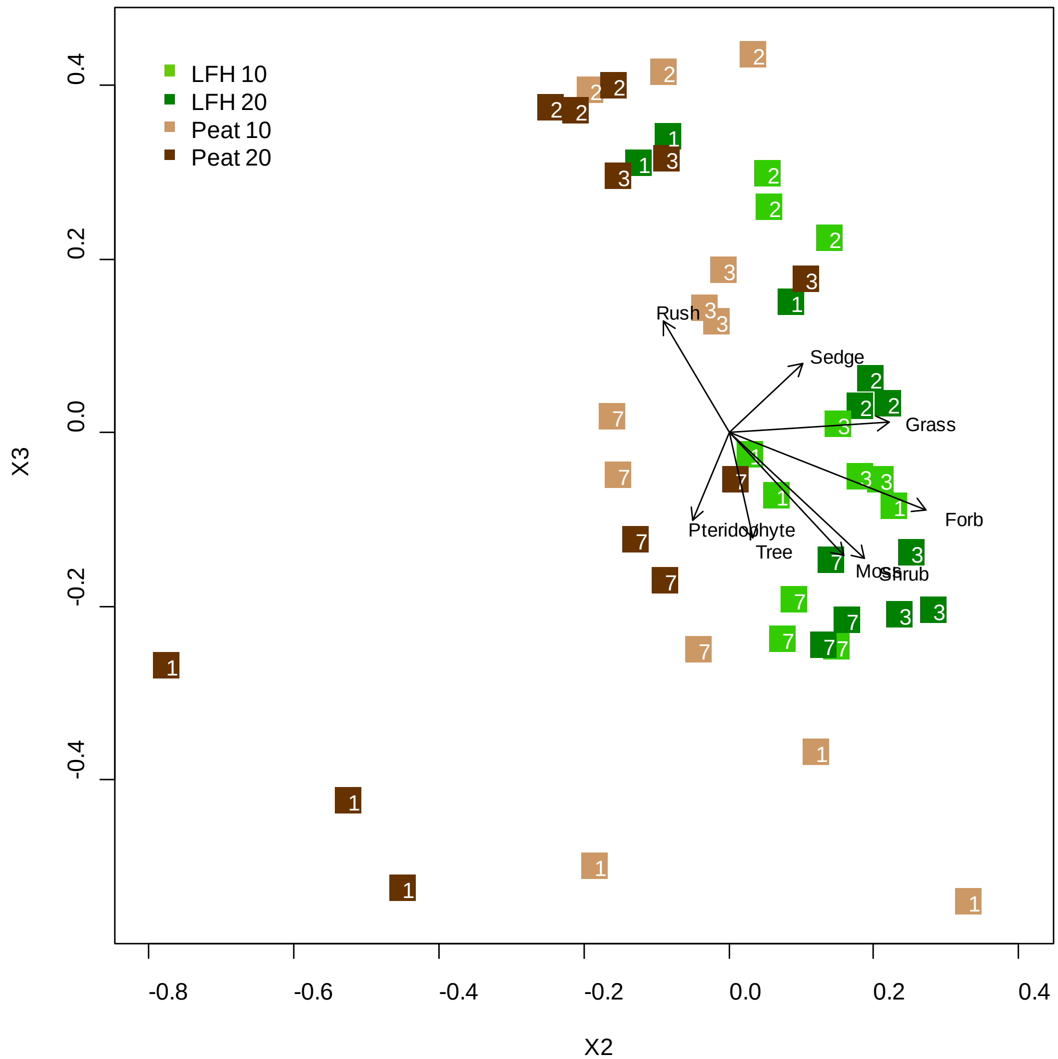

Figure 2.10. NMDS ordination (X2 vs X3) of growth form in years 1, 2, 3 and 7 after reclamation at W1 dump.

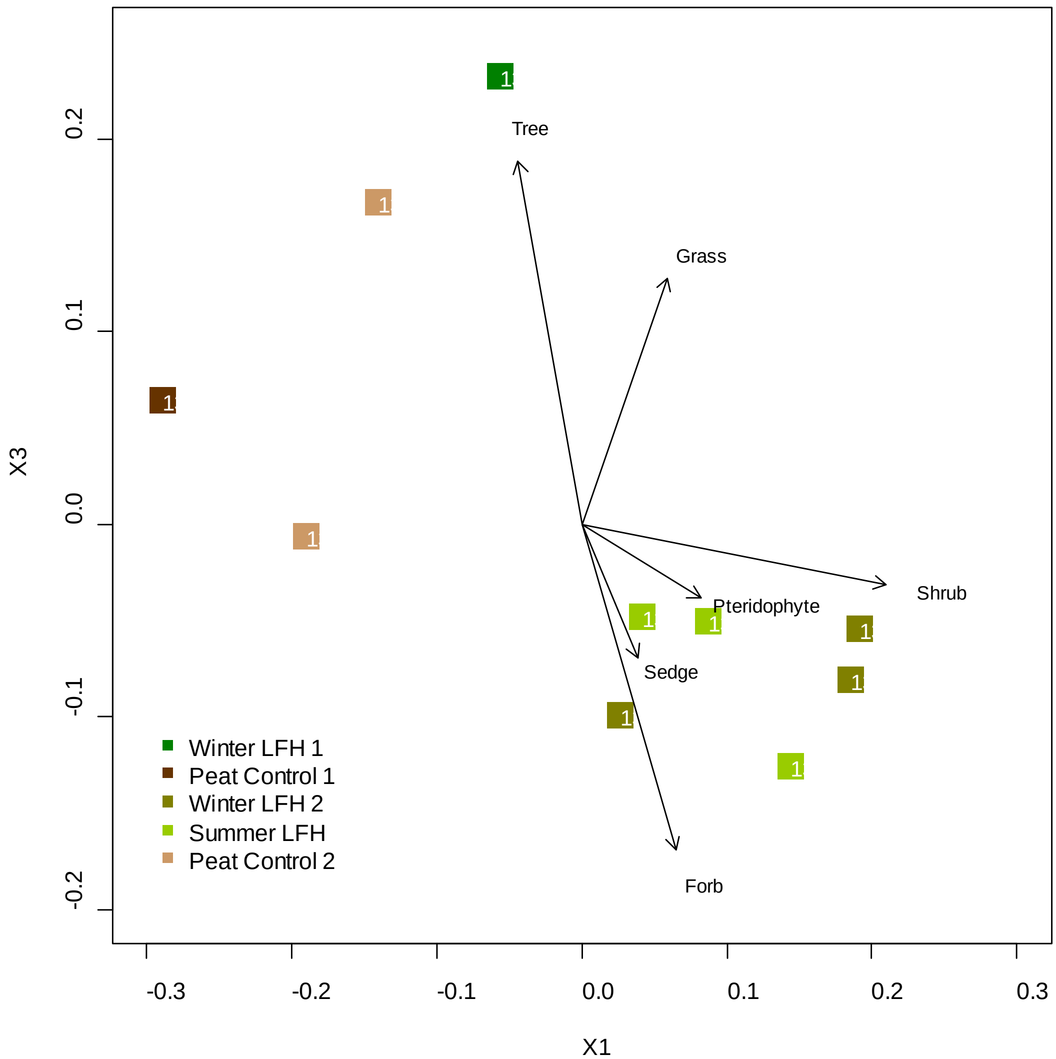

Figure 2.11. NMDS ordination (X1 vs X3) of growth form groups in year 13 after reclamation at MLSB.

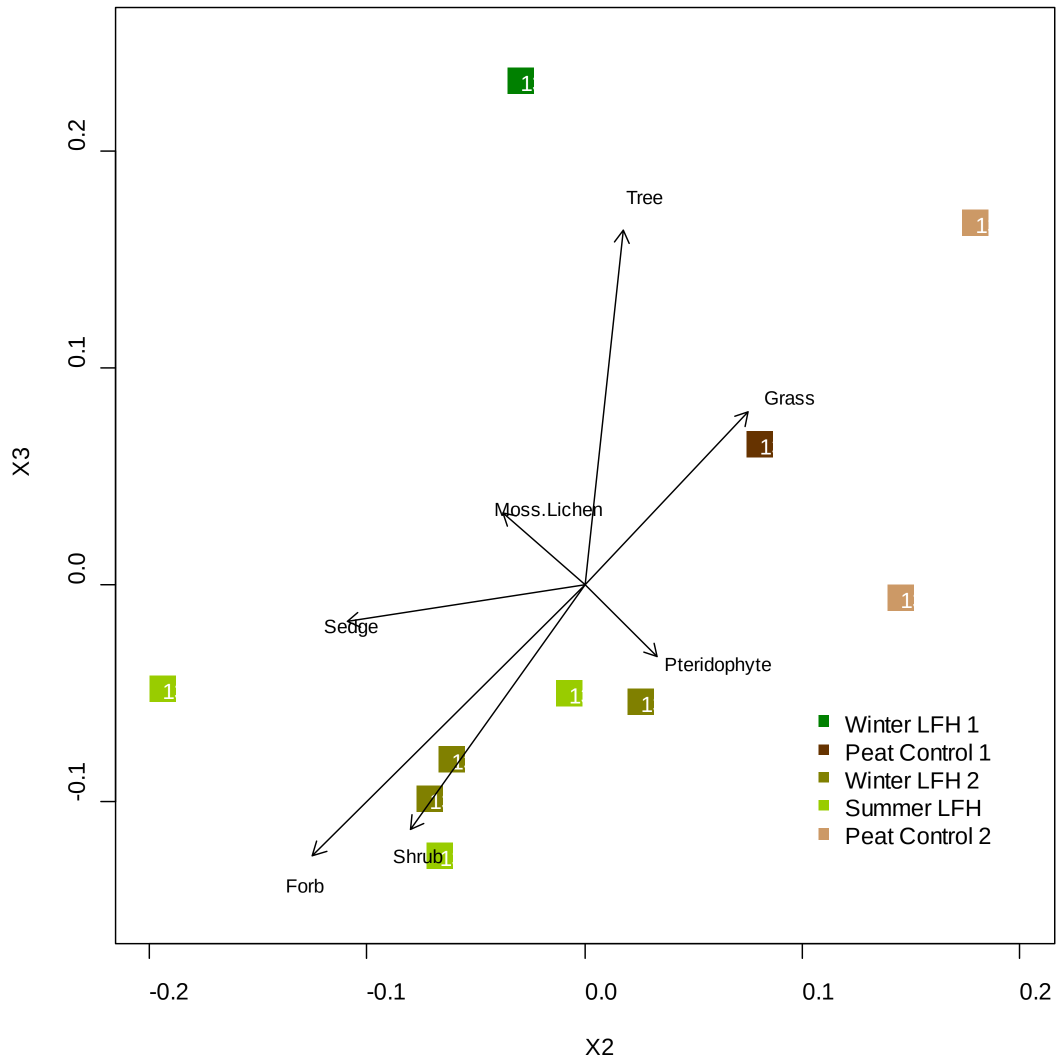

Figure 2.12. NMDS ordination (X2 vs X3) of growth form groups in year 13 after reclamation at MLSB.

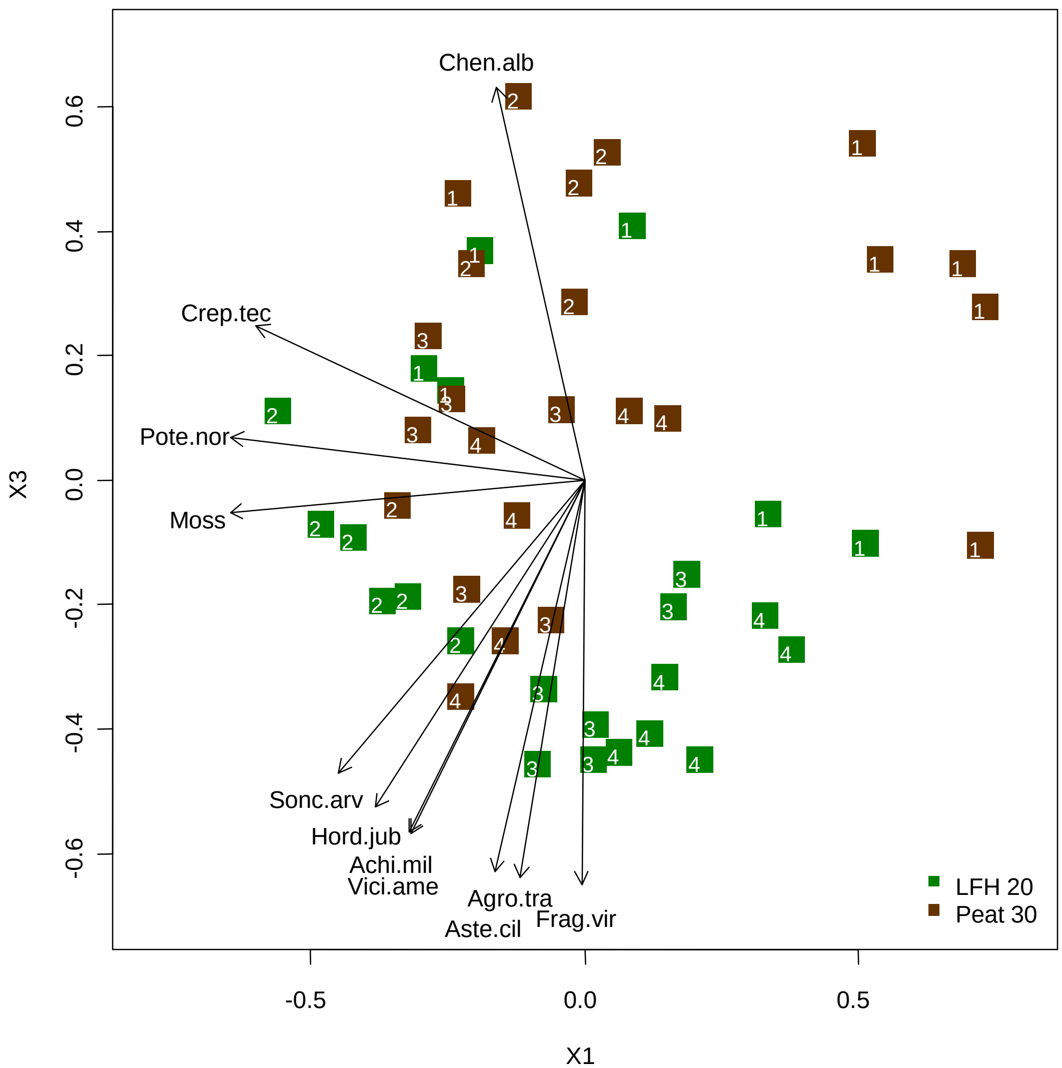

Figure 2.13. NMDS ordination (X1 vs X3) of species composition in years 1, 2, 3 and 4 after reclamation at SE dump. Vectors show species highly correlated with data (r > 0.5); less correlated vectors are not shown.

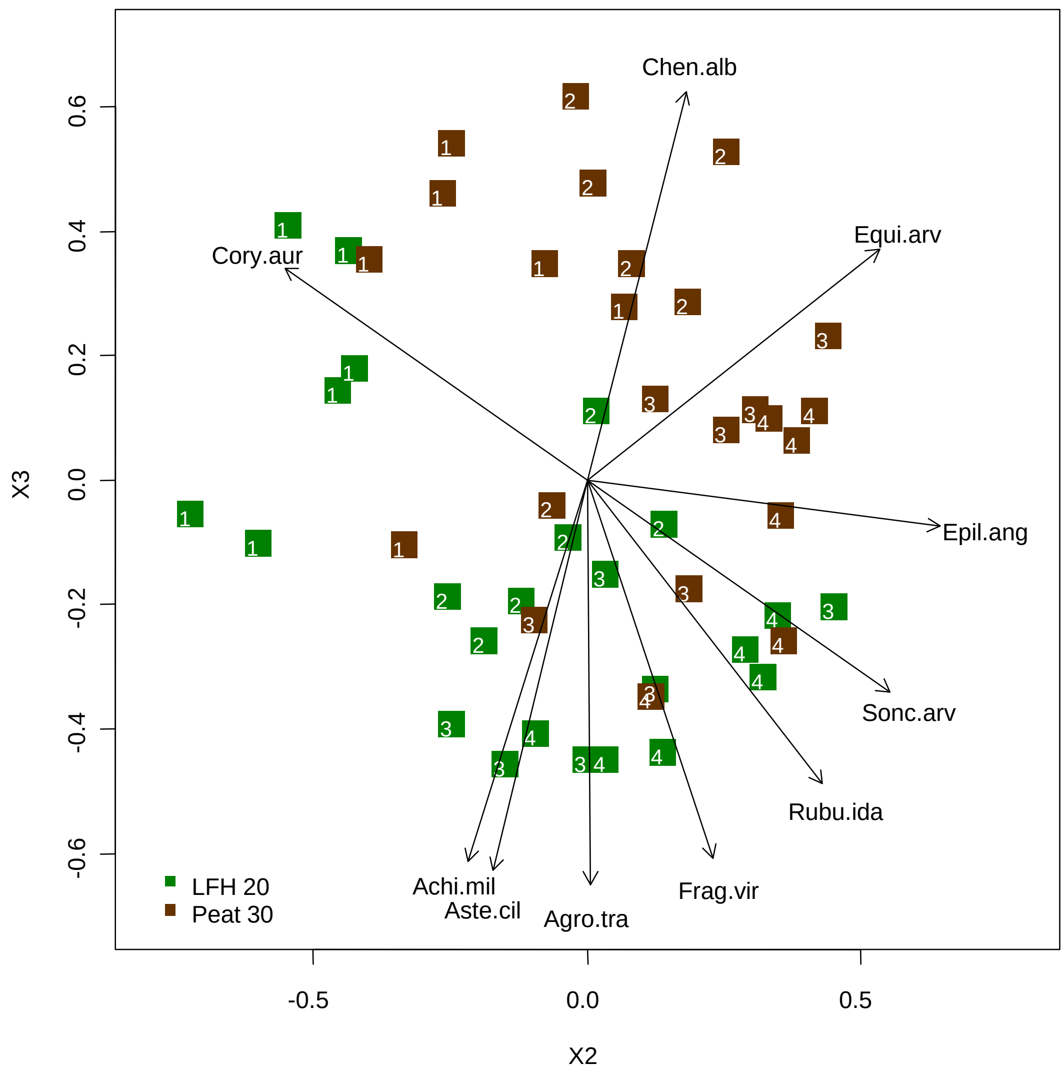

Figure 2.14. NMDS ordination (X2 vs X3) of species composition in years 1, 2, 3 and 4 after reclamation at SE dump. Vectors show species highly correlated with data (r > 0.5); less correlated vectors are not shown.

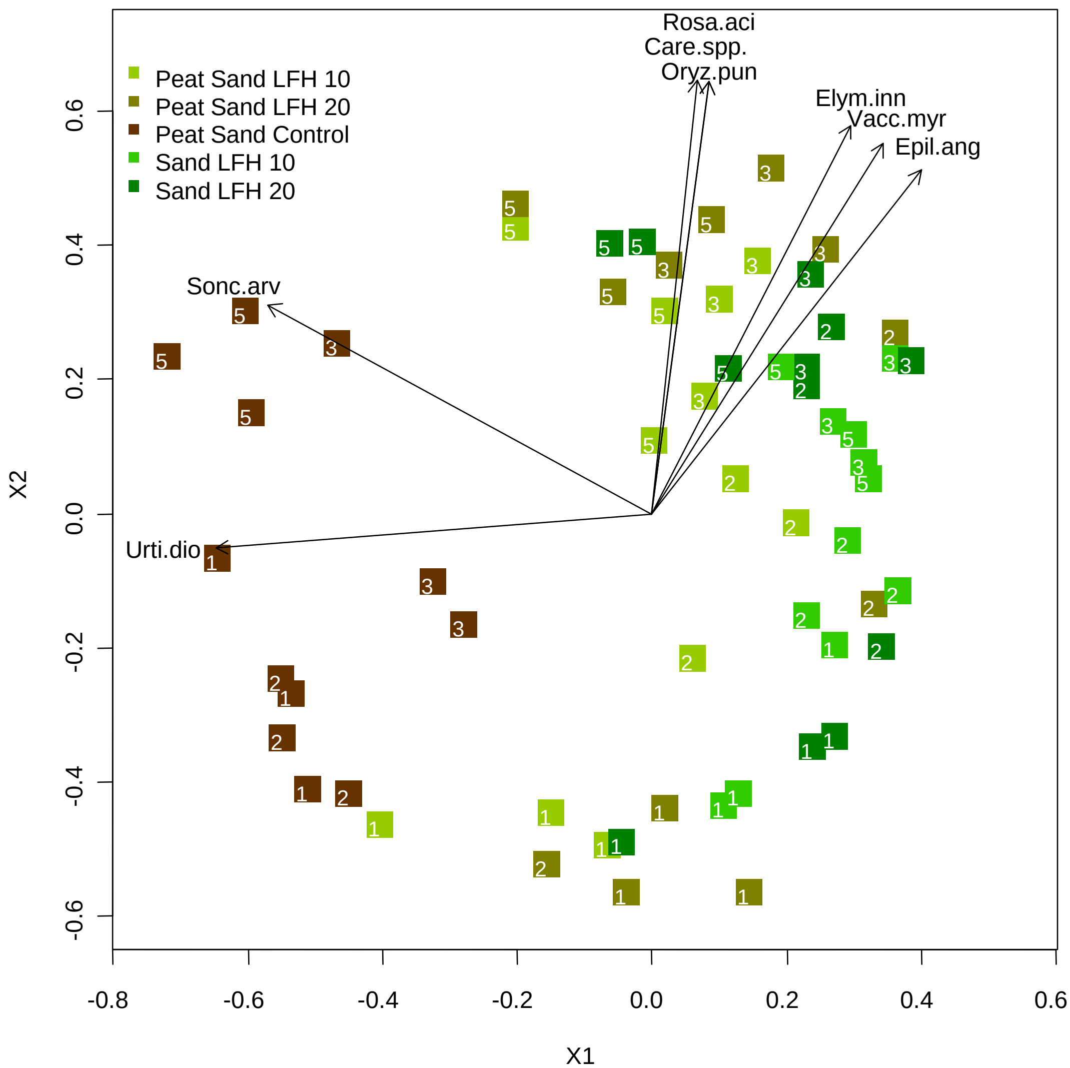

Figure 2.15. NMDS ordination (X1 vs X2) of species composition in years 1, 2, 3 and 5 after reclamation at Aurora. Vectors show species highly correlated with data (r > 0.5); less correlated vectors are not shown.

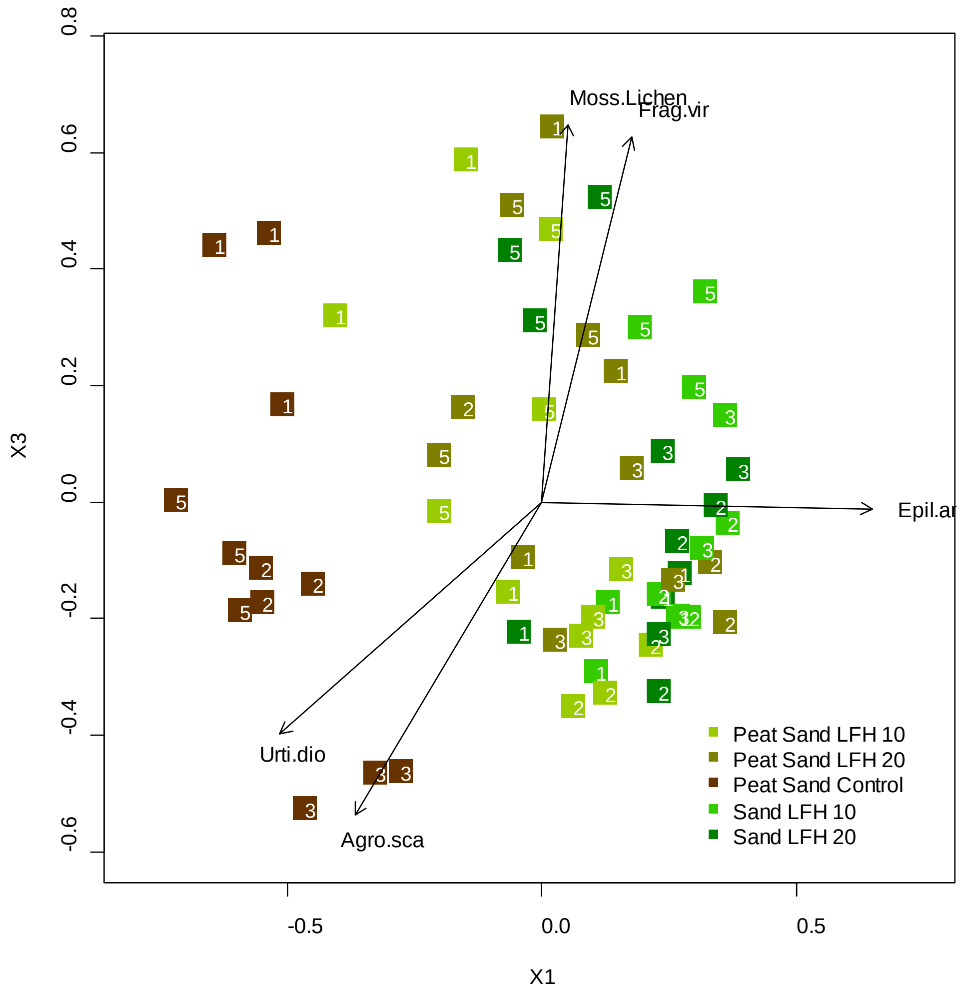

Figure 2.16. NMDS ordination (X1 vs X3) of species composition in years 1, 2, 3 and 5 after reclamation at Aurora. Vectors show species highly correlated with data (r > 0.5); less correlated vectors are not shown.

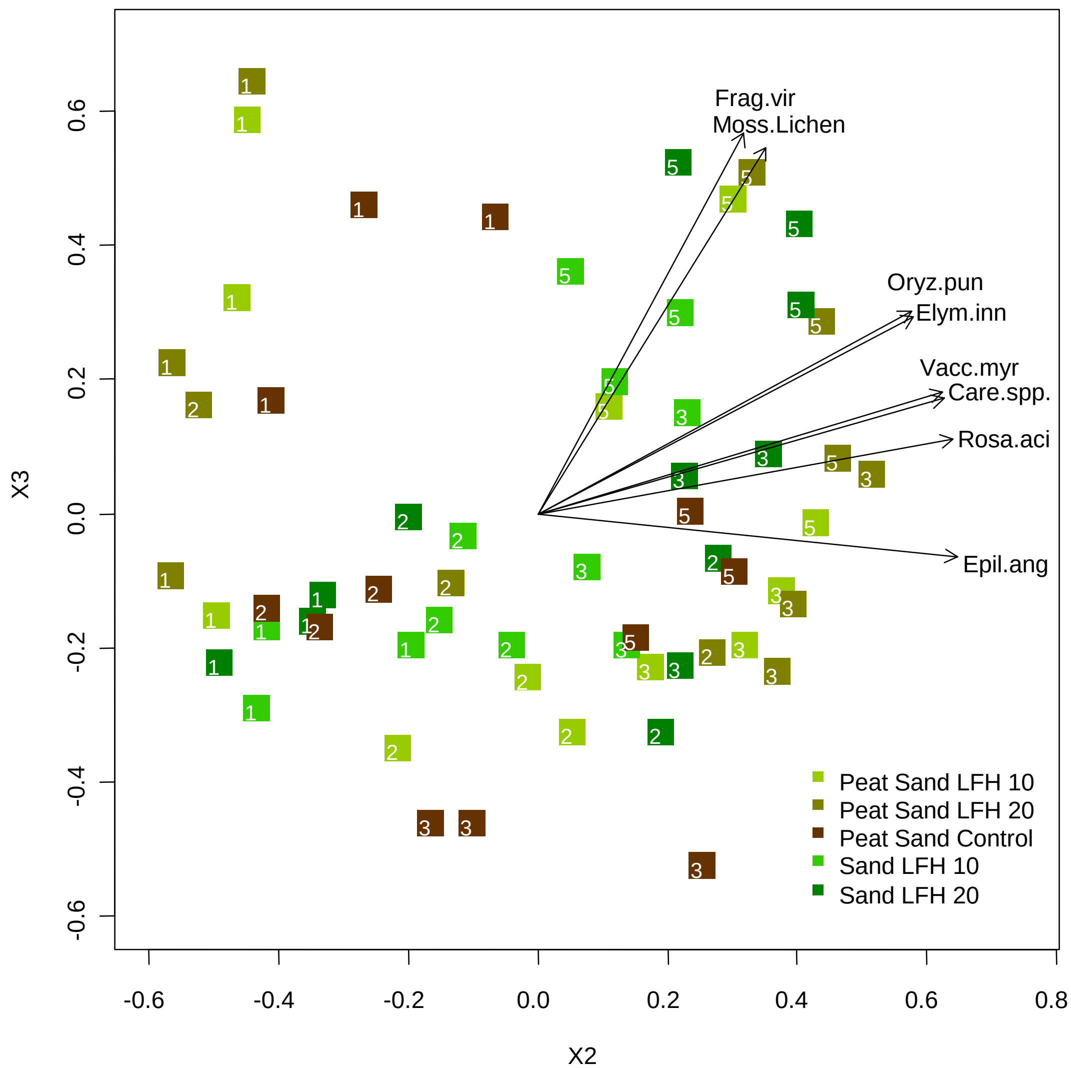

Figure 2.17. NMDS ordination (X2 vs X3) of species composition in years 1, 2, 3 and 5 after reclamation at Aurora. Vectors show species highly correlated with data (r > 0.5); less correlated vectors are not shown.

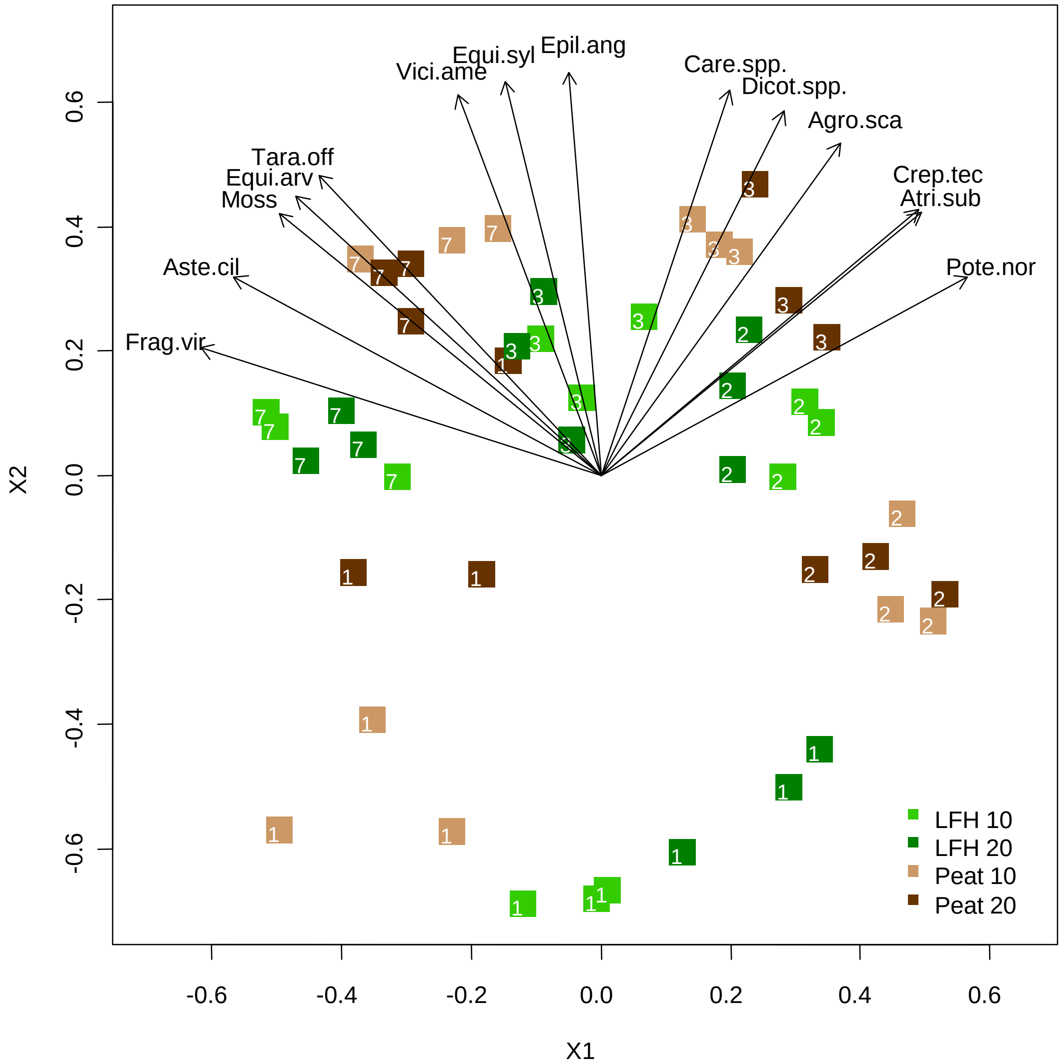

Figure 2.18. NMDS ordination (X1 vs X2) of species composition in years 1, 2, 3 and 7 after reclamation at W1 dump. Vectors show species highly correlated with data (r > 0.5); less correlated vectors are not shown.

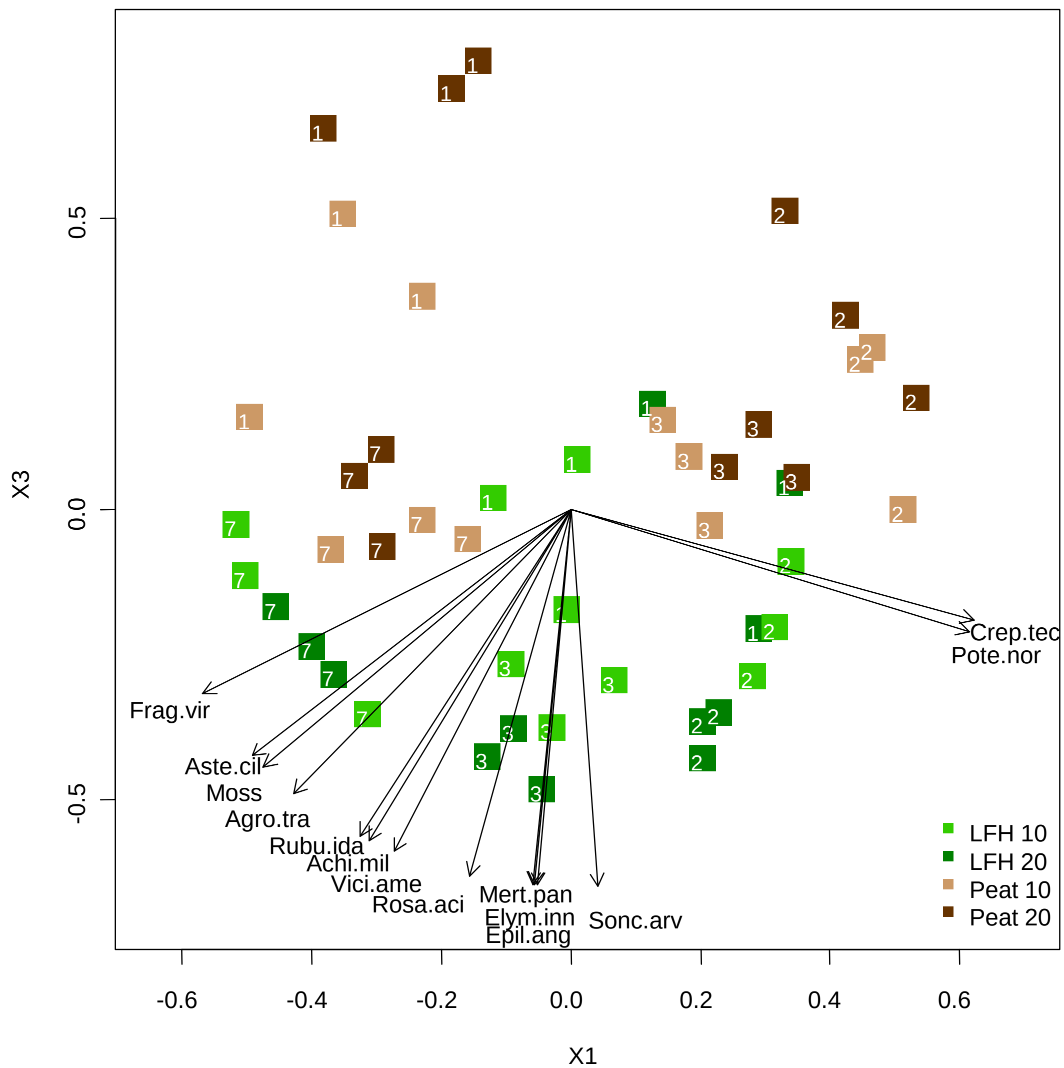

Figure 2.19. NMDS ordination (X1 vs X3) of species composition in years 1, 2, 3 and 7 after reclamation at W1 dump. Vectors show species highly correlated with data (r > 0.5); less correlated vectors are not shown.

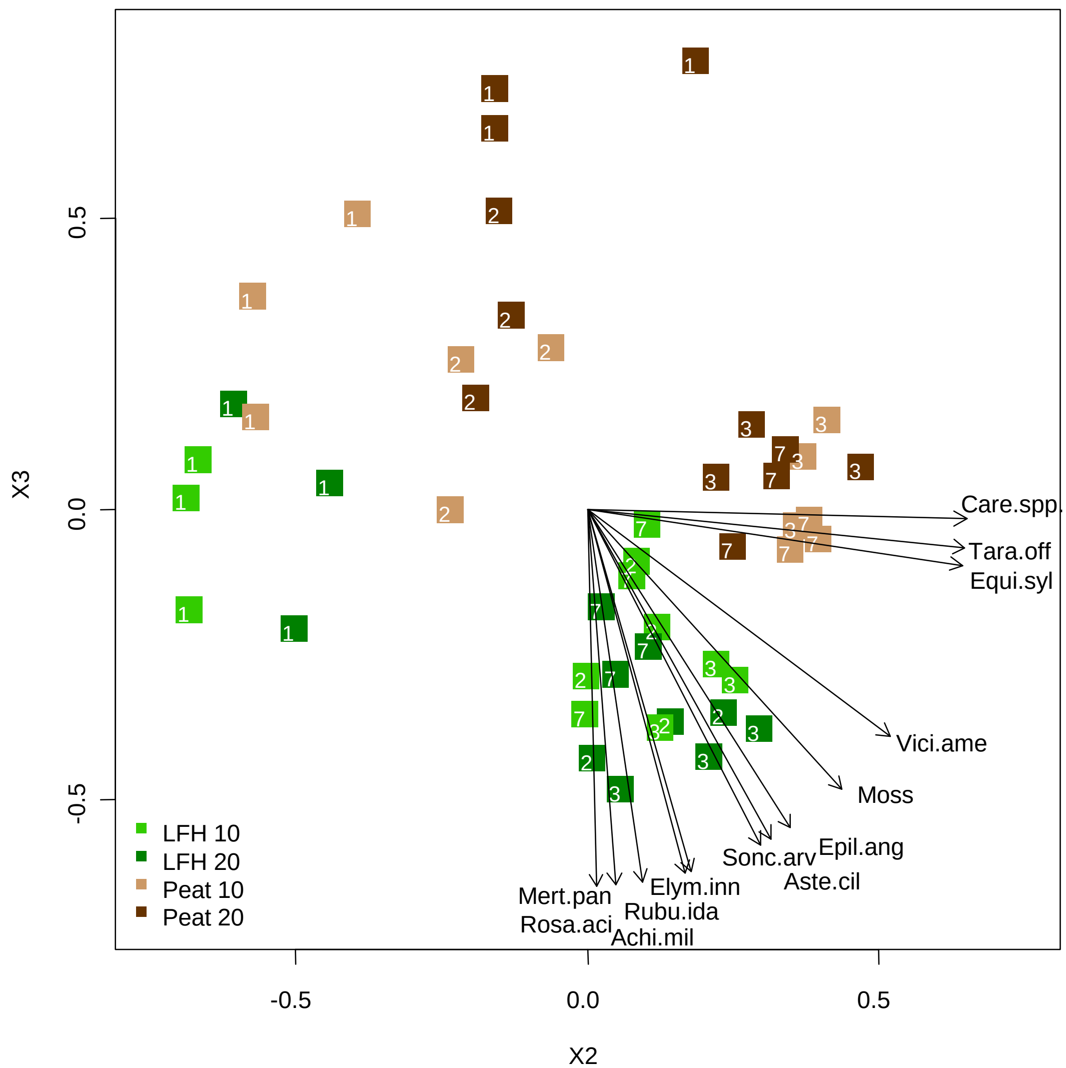

Figure 2.20. NMDS ordination (X2 vs X3) of species composition in years 1, 2, 3 and 7 after reclamation at W1 dump. Vectors show species highly correlated with data (r > 0.5); less correlated vectors are not shown.

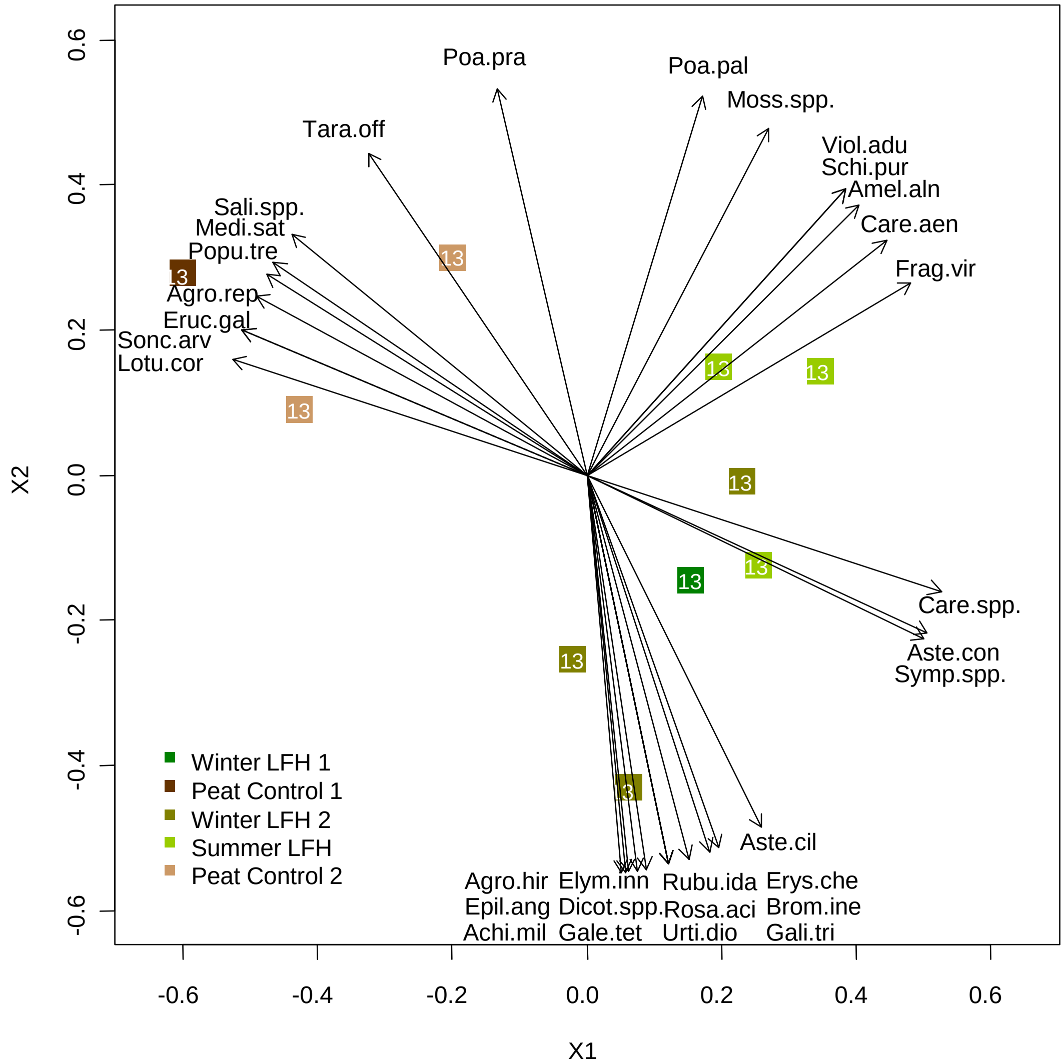

Figure 2.21. NMDS ordination (X1 vs X2) of species composition in year 13 after reclamation at MLSB. Vectors show species highly correlated with data (r > 0.5); less correlated vectors are not shown.

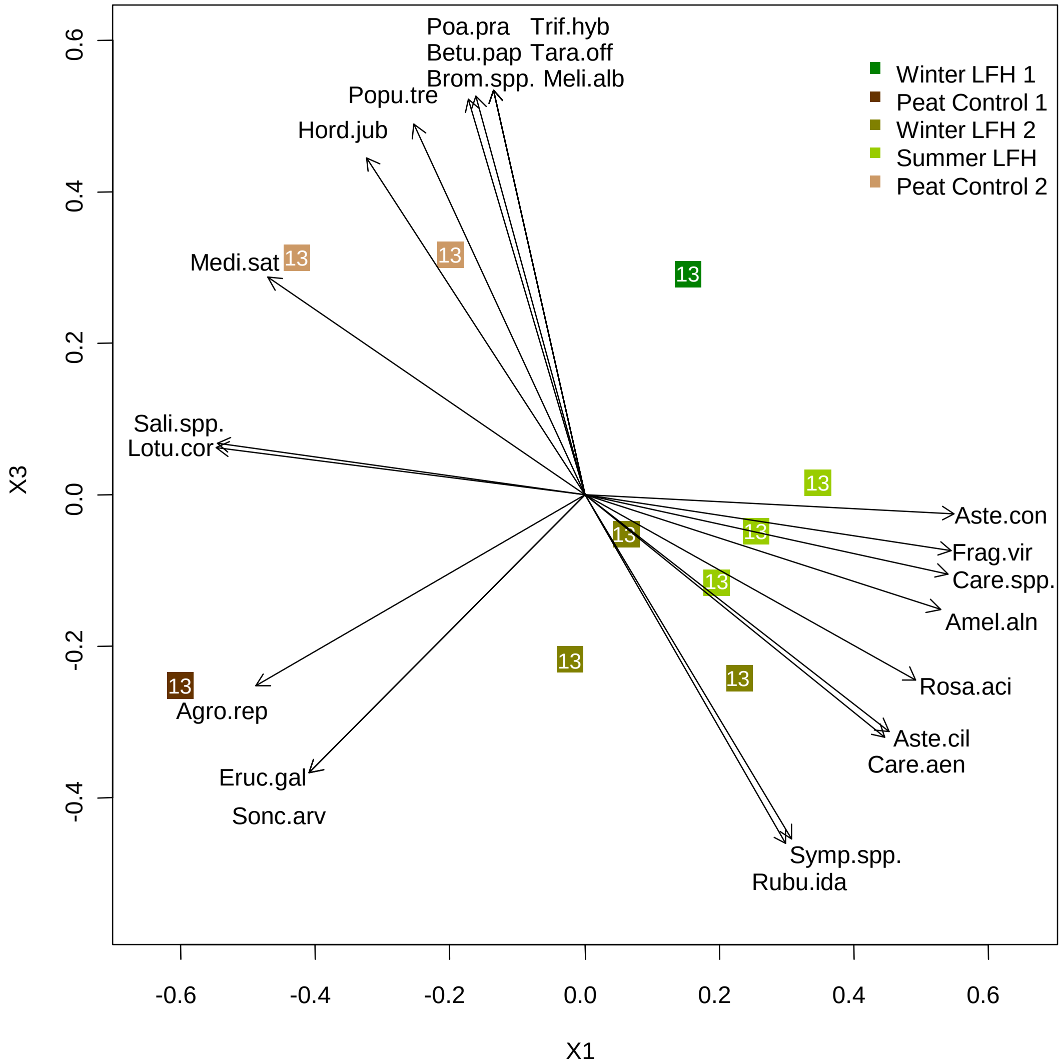

Figure 2.22. NMDS ordination (X1 vs X3) of species composition in year 13 after reclamation at MLSB. Vectors show species highly correlated with data (r > 0.5); less correlated vectors are not shown.

Table 2.1. Study site treatment information.

Site	Age	Substrate	Cover soil	LFH type	No. of replicates
SE dump	4	B/C horizon	20 cm LFH mineral soil mix	*Populus tremuloides*, *Picea glauca*	6
	4	Overburden	30 cm peat mineral soil mix		6
Aurora sand	5	Sand	10 cm LFH mineral soil mix	*Pinus banksiana*	3
	5	Sand	20 cm LFH mineral soil mix	*Pinus banksiana*	3
Aurora peat-sand	5	Peat-sand	100 cm peat-sand		3
	5	Peat-sand	10 cm LFH mineral soil mix	*Pinus banksiana*, *Populus tremuloides*	3
	5	Peat-sand	20 cm LFH mineral soil mix	*Pinus banksiana*, *Populus tremuloides*	3
W1 dump	7	Secondary	10 cm LFH mineral soil mix	*Populus tremuloides*	3
	7	Secondary	20 cm LFH mineral soil mix	*Populus tremuloides*	3
	7	Secondary	10 cm peat mineral soil mix		3
	7	Secondary	20 cm peat mineral soil mix		3
MLSB Cell 16	13	Secondary	18 cm LFH mineral soil mix	*Populus tremuloides*	1
	13	Secondary	18 cm peat mineral soil mix		1
MLSB Cell 18	13	Peat mineral soil mix over secondary	12 cm LFH mineral soil mix	*Populus tremuloides*	6
	13	Secondary	18 cm peat mineral soil mix		2

Age at final time of sampling.
LFH type refers to donor site vegetation.
Secondary is fine textured, non-saline and non-sodic material from either suitable upland soil or surficial geologic material salvaged to a depth not considered suitable for plants.

Table 2.2. Assessment dates and information.

Site	Year	Month	Quadrats (cm)	Quadrats per experimental unit	Area (m^2)	Type
SE dump	2008	July	100 x 100	15	15	Systematic
	2009	August	100 x 100	15	15	Systematic
	2010	Mid August	50 x 100	7	3.5	Systematic + walk through
	2011	July	100 x 100	7 to 9	7 to 9	Systematic
Aurora sand	2006	Mid July	100 x 100	30	30	Random
	2007	Mid July	100 x 100	30	30	Random
	2008	Mid July	100 x 100	30	30	Random
	2010	Mid August	50 x 100	11, 12	5.5	Systematic + walk through
Aurora peat-sand	2006	Mid July	100 x 100	30	30	Random
	2007	Mid July	100 x 100	30	30	Random
	2008	Mid July	100 x 100	30	30	Random
	2010	Mid August	50 x 100	11 to21	5.5 to 10.5	Systematic + walk through
W1 dump	2004	Late July	20 x 50	84	8.4	Systematic
	2005	Late July	20 x 50	112	11.2	Systematic
	2006	Late July and early August	20 x 50	110 to 112	11.2	Systematic
	2010	Mid August	50 x 100	14 (except 29 at Peat 20-1)	7	Systematic + walk through
MLSB	2010	Mid August	N/A	N/A	N/A	Walk through
	2011	Mid July	50 x 100	12	6	Systematic + walk through

Table 2.3. Monthly rainfall at SE dump at Suncor Millennium Mine from 2010 to 2011 and historical climate normals (1971-2000) for Fort McMurray airport.

	Rainfall (mm)		Historical normals	
Month	2010	2011	Rainfall (mm)	Air temperature (°C)
April	4.3	4.3	9	3.4
May	20.3	11.7	34	10.4
June	31.0	35.8	75	14.7
July	42.7	48.8	81	16.8
August	93.2	69.9	73	15.3
September	36.6	32.3	45	9.4
October	4.1	8.6	19	2.8
Total	232.1	211.3	336	

Data from Suncor's meteorological station database and historical data from Environment Canada (2013).

Table 2.4. Monthly rainfall at Syncrude Moose Mountain station at Aurora mine in 2006 to 2010 and historical climate normals (1971-2000) for Fort McMurray airport.

	Rainfall (mm)				Historical normals	
Month	2007	2008	2009	2010	Rainfall (mm)	Air temperature (°C)
April	10.0	1.0	13.9	6.2	9	3.4
May	24.5	5.9	18.1	32.1	34	10.4
June	50.4	36.4	100.1	28.6	75	14.7
July	57.8	47.7	35.4	74.4	81	16.8
August	49.9	95.2	70.6	57.0	73	15.3
September	40.0	27.5	20.9	62.1	45	9.4
October	4.4	33.7	15.6	4.4	19	2.8
Total	237.0	247.4	274.6	264.8	336	

Data from Syncrude's meteorological station database and historical data from Environment Canada (2013).

Table 2.5. Monthly rainfall at Syncrude W1 overburden station in 2005 to 2011 and historical climate normals (1971-2000) for Fort McMurray airport.

	Rainfall (mm)							Historical normals	
Month	2005	2006	2007	2008	2009	2010	2011	Rainfall (mm)	Air temperature (°C)
April	0.3	5.8	14.2	2.5	12.5	22.0	3.1	9	3.4
May	30.7	46.6	16.2	5.6	17.6	44.1	11.7	34	10.4
June	72.1	32.6	27.9	67.3	86.9	27.1	54.7	75	14.7
July	132.7	131.0	45.3	67.5	38.8	51.7	60.4	81	16.8
August	69.9	35.8	96.2	115.1	78.1	137.2	34.2	73	15.3
September	10.2	41.4	17.5	23.0	15.1	44.2	33.9	45	9.4
October	1.6	3.4	5.6	17.4	18.3	6.2	-	19	2.8
Total	317.5	296.6	222.9	298.4	267.3	332.5	198.0	336	

Data from Syncrude's meteorological station database and historical data from Environment Canada (2013).

Table 2.6. Monthly rainfall at MLSB Cell 18 station in 2004 to 2008 and historical climate normals (1971-2000) for Fort McMurray airport.

	Rainfall (mm)					Historical normals	
Month	2004	2005	2006	2007	2008	Rainfall (mm)	Air temperature (°C)
April	2.8	30.3	0.3	0.0	0.8	9	3.4
May	45.5	40.7	22.7	4.9	6.1	34	10.4
June	9.9	37.0	39.0	28.5	99.7	75	14.7
July	60.4	97.2	113.7	81.5	62.4	81	16.8
August	28.4	31.4	36.4	71.8	94.1	73	15.3
September	75.6	6.5	28.1	31.8	27.9	45	9.4
October	9.5	1.1	0.5	6.3	15.9	19	2.8
Total	232.1	244.2	240.7	224.8	306.9	336	

Data from Suncrude's meteorological station database and historical data from Environment Canada (2013).

Table 2.7. Mean woody plant density at SE dump in the first four years after reclamation.

	Woody plant density (plants / m^2)	
Year	LFH mineral soil mix	Peat mineral soil mix
2008	1.0 (0.5/1.4)$^{a/C}$	0.1 (0.0/0.2)$^{b/C}$
2009	2.0 (1.9/3.5)$^{a/BC}$	0.6 (0.1/3.5)$^{b/BC}$
2010	2.9 (1.6/3.6)$^{a/B}$	1.3 (0.3/3.8)$^{b/B}$
2011	12.1 (8.3/16.2)^{A}	7.8 (2.4/18.8)^{A}

Numbers are medians with 5th/95th percentiles in brackets, n = 6.
2008, 2009 data from Brown (2010), 2011 data from Forsch (unpublished).
Different lower case letters indicate significant differences between treatments within years at $p < 0.1$.
Different upper case letters indicate significant differences between years within treatments at $p < 0.1$.

Table 2.8. Mean woody plant density at Aurora in the first five years after reclamation.

			Woody plant density (plants / m^2)	
Year	Cover soil	Application depth (cm)	Sand	Peat-sand
2006	LFH mineral soil mix	10	3.8 (0.8)$^{a/b}$	2.7 (0.7)^{b}
	LFH mineral soil mix	20	5.7 (0.6)$^{a/B}$	4.3 (1.4)^{ab}
	Peat mineral soil mix	-		0.0 (0.0)$^{c/B}$
2007	LFH mineral soil mix	10	5.0 (0.9)^{b}	3.5 (0.4)^{b}
	LFH mineral soil mix	20	8.99 (0.5)$^{a/A}$	3.5 (0.3)^{b}
	Peat mineral soil mix	-		0.1 (0.0)$^{c/AB}$
2008	LFH mineral soil mix	10	5.4 (1.0)$^{a/b}$	5.2 (1.1)^{b}
	LFH mineral soil mix	20	8.3 (0.6)$^{a/A}$	4.1 (1.0)^{b}
	Peat mineral soil mix	-		0.3 (0.1)$^{c/A}$
2010	LFH mineral soil mix	10	7.0 (.21)^{ab}	5.2 (0.1)^{b}
	LFH mineral soil mix	20	9.0 (0.9)$^{a/A}$	5.6 (1.2)^{ab}
	Peat mineral soil mix	-		0.4 (0.0)$^{c/A}$

Numbers are means with standard errors in brackets, n = 3.
2006, 2007, 2008 data from Mackenzie (2012a).
Lower case letters indicate significant differences between treatment combinations within years at $p < 0.05$.
Upper case letters indicate significant differences between years within treatment combinations at $p < 0.05$.

Table 2.9. Mean woody plant density at W1 dump in the first seven years after reclamation.

Year	Application depth (cm)	Woody plant density (plants / m^2)	
		LFH mineral soil mix	Peat mineral soil mix
2004	10	1.2 (0.2)$^{a/C}$	0.3 (0.2)$^{b/C}$
	20	2.3 (0.7)$^{a/C}$	0.5 (0.2)$^{b/C}$
2005	10	0.8 (0.2)$^{a/C}$	0.6 (0.2)$^{b/C}$
	20	1.7 (0.1)$^{a/C}$	0.2 (0.1)$^{b/C}$
2006	10	9.0 (3.2)^{B}	7.7 (2.0)^{B}
	20	8.3 (1.2)^{B}	3.7 (2.8)^{B}
2010	10	4.0 (1.2)^{A}	2.2 (1.0)^{A}
	20	3.0 (0.1)^{A}	3.2 (0.6)^{A}

Numbers are means with standard errors in brackets, n = 6.
2004, 2005, 2006 data from Mackenzie (2006) and Mackenzie (unpublished).
Lower case letters indicate significant differences between treatment combinations within years at $p < 0.05$.
Upper case letters indicate significant differences between years within treatment combinations at $p < 0.05$.

Table 2.10. Mean woody plant density at MLSB Cells 16 and 18 thirteen years after reclamation.

Site	Cover soil	Application depth (cm)	Application season	Woody plant density (plants / m^2)
Cell 16	LFH mineral soil mix	18	Winter	7.5
	Peat mineral soil mix	18	Unknown	1.0
Cell 18	LFH mineral soil mix	12	Winter	12.3 (0.5)^{a}
	LFH mineral soil mix	12	Summer	10.8 (2.0)^{a}
	Peat mineral soil mix	18	Unknown	1.3 (0.5)^{b}

Numbers are means with standard errors in brackets, n = 1 at Cell 16, n = 3 for LFH mineral soil mix at Cell 18, n = 2 for peat mineral soil mix at Cell 18.
Different lower case letters indicate significant differences between treatments at $p < 0.05$.

Table 2.11. Total species richness on research sites of different ages.

Site	Age	Treatment	Application depth (cm)	Total richness
SE dump	4	LFH mineral soil mix	20	86
	4	Peat mineral soil mix	30	85
Aurora	5	LFH mineral soil mix on peat-sand	10	66
	5	LFH mineral soil mix on peat-sand	20	61
	5	LFH mineral soil mix on sand	10	48
	5	LFH mineral soil mix on sand	20	52
	5	Peat mineral soil mix	100	55
W1 dump	7	LFH mineral soil mix	10	93
	7	LFH mineral soil mix	20	100
	7	Peat mineral soil mix	10	90
	7	Peat mineral soil mix	20	87
Cell 16	13	LFH mineral soil mix on secondary	18	66
	13	Peat mineral soil mix on secondary	18	39
Cell 18	13	Winter placed LFH mineral soil mix	12	84
	13	Summer placed LFH mineral soil mix	12	73
	13	Peat mineral soil mix on secondary	18	66

Total species richness was calculated by combining species from all experimental units from all years of assessment and removing duplicates.

Table 2.12. Mean experimental unit species richness at SE dump in the first four years after reclamation.

	Experimental unit richness		Estimated richness (Chao 2)		Experimental unit native richness		Estimated native richness (Chao 2)	
Year	LFH mineral soil mix	Peat mineral soil mix	LFH mineral soil mix	Peat mineral soil mix	LFH mineral soil mix	Peat mineral soil mix	LFH mineral soil mix	Peat mineral soil mix
2008	24.3 (3.0)[a]	14.0 (2.9)[b]	27.5 (8.9)	16.6 (9.5)	21.2 (2.7)[a]	11.7 (2.1)[b]	24.3 (8.3)	13.6 (6.9)
2009	35.8 (2.0)[a]	26.3 (2.4)[b]	38.8 (3.9)	31.2 (5.2)	31.3 (1.7)[a]	20.8 (2.1)[b]	34.1 (2.7)	25.9 (4.8)
2010	25.8 (1.4)	22.7 (1.0)	30.3 (8.1)	26.7 (3.9)	22.0 (1.4)	17.2 (0.9)	26.0 (6.8)	20.1 (3.7)
2010 with walk through	31.8 (1.9)	29.3 (1.0)			27.7 (2.0)	23.5 (1.0)		
2011	30.0 (1.9)	26.3 (2.2)	37.3 (9.6)	38.8 (21.8)	25.7 (1.6)	22.2 (2.2)	31.8 (8.0)	33.6 (22.2)
2011 with walk through	34.7 (1.4)	32.8 (2.7)			30.0 (1.3)	28.3 (2.5)		

Experimental unit richness was obtained by averaging experimental unit values, numbers are means with standard errors in brackets, n = 6.
Estimated richness using Chao 2 bias corrected formula (Colwell 2013), numbers are means with standard deviations in brackets, n = 6.
2008, 2009 data from Brown (2010), 2011 data from Forsch (unpublished).
Lower case letters indicate significant differences between treatments within years at $p < 0.05$. In 2010 and 2011 data that did not include a walk through was not analyzed statistically.

Table 2.13. Mean experimental unit species richness at Aurora in the first five years after reclamation.

			Experimental unit richness		Estimated richness (Chao 2)	
Year	Cover soil	Application depth (cm)	Sand	Peat-sand	Sand	Peat-sand
2006	LFH mineral soil mix	10	21.0 (21.0/21.9)^{a}	21.0 (21.0/24.6)^{a}	22.4 (0.7)	26.9 (2.0)
	LFH mineral soil mix	20	22.0 (19.3/23.8)^{a}	22.0 (18.4/25.6)^{a}	24.6 (6.1)	30.0 (7.7)
	Peat mineral soil mix	-		10.0 (10.0/10.0)^{b}		13.1 (2.5)
2007	LFH mineral soil mix	10	26.0 (25.1/30.5)	27.0 (24.3/27.0)	34.2 (9.0)	30.5 (2.1)
	LFH mineral soil mix	20	29.0 (25.4/31.7)	27.0 (24.3/27.9)	33.0 (5.6)	29.9 (3.5)
	Peat mineral soil mix	-		17.0 (16.1/21.5)		25.9 (8.6)
2008	LFH mineral soil mix	10	25.7 (1.2)	30.3 (4.1)	31.3 (5.6)	36.7 (13.0)
	LFH mineral soil mix	20	25.7 (2.4)	27.7 (2.0)	33.6 (11.0)	34.8 (5.7)
	Peat mineral soil mix	-		19.3 (0.9)		24.3 (4.8)
2010	LFH mineral soil mix	10	19.3 (1.2)	25.0 (1.5)	22.5 (4.0)	33.5 (3.0)
	LFH mineral soil mix	20	19.3 (1.5)	19.0 (0.6)	24.8 (6.3)	23.4 (3.6)
	Peat mineral soil mix	-		16.0 (1.0)		25.1 (6.8)
2010	LFH mineral soil mix	10	23.7 (1.5)^{b}	35.0 (3.2)^{a}		
with walkthrough	LFH mineral soil mix	20	25.3 (1.7)^{ab}	27.0 (2.6)^{ab}		
	Peat mineral soil mix	-		24.0 (1.2)^{b}		

Experimental unit richness obtained by averaging experimental unit values.
Estimated values using Chao 2 bias corrected formula (Colwell 2013).
Numbers are means with standard errors in brackets for normal data and medians with 5th/95th percentiles for non-normal data. For estimated richness numbers are means with standard deviations in brackets. n = 3.
2006, 2007, 2008 data from Mackenzie (2012a).
Lower case letters indicate significant differences between treatment combinations within years at $p < 0.05$.

Table 2.14. Mean experimental unit native species richness at Aurora in the first five years after reclamation.

			Experimental unit native richness		Estimated native richness (Chao 2)	
Year	Cover soil	Application depth (cm)	Sand	Peat-sand	Sand	Peat-sand
2006	LFH mineral soil mix	10	21.0 (20.1/21.9)[a]	20.0 (20.0/23.6)[a]	22.1 (1.2)	25.0 (2.3)
	LFH mineral soil mix	20	22.0 (19.3/23.8)[a]	22.0 (17.5/24.7)[a]	24.6 (6.1)	27.0 (4.2)
	Peat mineral soil mix	-		8.0 (8.0/8.9)[b]		10.3 (1.9)
2007	LFH mineral soil mix	10	23.0 (23.0/27.5)	24.0 (21.3/24.0)	32.0 (9.5)	26.1 (2.0)
	LFH mineral soil mix	20	26.0 (23.3/29.6)	24.0 (21.3/26.7)	30.1 (4.9)	27.0 (5.2)
	Peat mineral soil mix	-		14.0 (12.2/18.5)		19.8 (8.1)
2008	LFH mineral soil mix	10	24.3 (0.9)[ab]	27.7 (3.8)[a]	29.4 (4.4)	32.6 (11.8)
	LFH mineral soil mix	20	24.0 (2.1)[ab]	26.0 (2.1)[ab]	30.1 (8.5)	33.3 (7.0)
	Peat mineral soil mix	-		15.3 (0.9)[b]		19.4 (4.7)
2010	LFH mineral soil mix	10	19.0 (1.0)	23.3 (1.2)	21.8 (3.5)	30.5 (0.9)
	LFH mineral soil mix	20	18.7 (1.5)	18.3 (0.3)	23.6 (6.2)	22.7 (4.3)
	Peat mineral soil mix	-		14 (0.6)		25.2 (9.0)
2010	LFH mineral soil mix	10	23.0 (21.2/24.8)	31.0 (29.2/36.4)		
with walkthrough	LFH mineral soil mix	20	25.0 (22.3/25.69)	24.0 (21.3/30.3)		
	Peat mineral soil mix	-		20.0 (20.0/22.7)		

Experimental unit richness obtained by averaging experimental unit values.
Estimated values using Chao 2 bias corrected formula (Colwell 2013).
Numbers are means with standard errors in brackets for normal data and medians with $5^{th}/95^{th}$ percentiles for non-normal data. For estimated richness numbers are means with standard deviations in brackets. n = 3.
2006, 2007, 2008 data from Mackenzie (2012a).
Lower case letters indicate significant differences between treatment combinations within years at $p < 0.05$.

Table 2.15. Mean experimental unit species richness at W1 dump in the first seven years after reclamation.

Year	Application depth (cm)	Experimental unit richness		Estimated richness (Chao 2)		Experimental unit native richness		Estimated native richness (Chao 2)	
		LFH mineral soil mix	Peat mineral soil mix	LFH mineral soil mix	Peat mineral soil mix	LFH mineral soil mix	Peat mineral soil mix	LFH mineral soil mix	Peat mineral soil mix
2004	10	19.0 (2.5)[a]	6.3 (1.9)[b]	26.5 (4.9)	7.6 (3.8)	18.0 (2.5)[a]	5.3 (1.5)[b]	26.3 (5.2)	6.9 (2.2)
	20	21.0 (3.2)[a]	7.0 (0.6)[b]	25.4 (6.7)	11.0 (5.2)	18.3 (3.0)[a]	6.7 (0.3)[b]	22.3 (5.7)	10.4 (5.6)
2005	10	37.3 (1.9)[a]	21.0 (2.5)[b]	44.7 (3.2)	30.9 (9.7)	32.0 (2.1)[a]	18.3 (1.9)[b]	38.1 (4.3)	27.8 (9.7)
	20	40.7 (1.2)[a]	20.0 (2.5)[b]	47.1 (5.8)	25.6 (6.8)	35.7 (1.2)[a]	16.7 (3.0)[b]	40.6 (2.6)	20.4 (7.4)
2006	10	41.7 (1.5)[a]	34.0 (2.3)[b]	52.0 (6.9)	50.7 (16.3)	37.3 (0.9)[a]	29.7 (2.4)[b]	46.4 (5.5)	46.2 (16.9)
	20	42.3 (2.9)[a]	30.3 (2.3)[b]	46.7 (7.1)	36.3 (7.3)	37.3 (2.6)[a]	26.3 (2.4)[b]	41.4 (6.9)	31.9 (7.0)
2010 without walkthrough	10	31.3 (0.9)	25.3 (1.5)	35.0 (3.6)	28.8 (5.1)	27.0 (1.2)	21.7 (1.2)	31.0 (4.1)	24.6 (3.8)
	20	31.3 (0.9)	28.3 (1.8)	42.9 (6.6)	32.9 (1.3)	27.7 (0.9)	23.3 (1.8)	41.8 (8.5)	25.6 (2.0)
2010 with walkthrough	10	44.7 (0.7)	45.3 (4.2)			38.0 (1.7)	38.7 (2.8)		
	20	46.3 (0.9)	39.3 (1.5)			39.3 (1.8)	33.7 (1.2)		

Experimental unit richness was obtained by averaging experimental unit values, numbers are means with standard errors in brackets, n = 3

Estimated using the Chao 2 bias corrected formula (Colwell 2013), numbers are means with standard deviations in brackets, n = 3.

2004, 2005, 2006 data from Mackenzie (2006), Mackenzie (unpublished).

Lower case letters indicate significant differences between treatment combinations within years at $p < 0.05$.

Table 2.16. Mean experimental unit species richness at MLSB twelve and thirteen years after reclamation.

Year	Site	Cover soil	Application depth (cm)	Application season	Experimental unit richness	Experimental unit native richness	Experimental unit non-native richness
2010	Cell 16	LFH mineral soil mix	18	Winter	53.0	40.0	13.0
		Peat mineral soil mix	18	Unknown	32.0	19.0	13.0
	Cell 18	LFH mineral soil mix	12	Winter	53.0 (2.6)	40.7 (2.2)	12.3 (0.7)
		LFH mineral soil mix	12	Summer	47.3 (1.2)	36.3 (1.5)	11.0 (0.6)
		Peat mineral soil mix	18	Unknown	41.5 (3.5)	30.0 (5.0)	11.5 (1.5)
2011	Cell 16	LFH mineral soil mix	18	Winter	45.0	33.0	12.0
		Peat mineral soil mix	18	Unknown	26.0	17.0	9.0
	Cell 18	LFH mineral soil mix	12	Winter	41.0 (1.5)	33.3 (2.0)	7.7 (0.9)
		LFH mineral soil mix	12	Summer	44.0 (1.7)	34.7 (1.7)	9.3 (0.3)
		Peat mineral soil mix	18	Unknown	40.5 (3.5)	26.5 (1.5)	14.0 (2.0)

Experimental unit richness obtained by averaging experimental unit values.
Numbers are means with standard errors in brackets for normal data, n = 1 at Cell 16, n = 3 for LFH mineral soil mix at Cell 18, n = 2 for peat mineral soil mix at Cell 18.
There were no significant differences between treatment combinations within years at $p < 0.05$.

Table 2.17. Mean Smith Wilson evenness and Shannon index of diversity at SE dump in the first four years after reclamation.

	Smith Wilson evenness		Shannon index of diversity	
Year	LFH mineral soil mix	Peat mineral soil mix	LFH mineral soil mix	Peat mineral soil mix
2008	0.1 (0.0)^{AB}	0.1 (0.0)^{AB}	2.1 (0.1)$^{a/B}$	1.5 (0.2)$^{b/B}$
2009	0.1 (0.0)^{C}	0.1 (0.0)^{C}	2.4 (0.1)^{A}	2.2 (0.2)^{A}
2010	0.1 (0.0)^{A}	0.2 (0.0)^{A}	2.5 (0.1)^{A}	2.4 (0.1)^{A}
2011	0.1 (0.0)^{BC}	0.1 (0.0)^{BC}	2.3 (0.0)^{A}	2.3 (0.2)^{A}

Numbers are means with standard errors in brackets, n = 6.
2008, 2009 data from Brown (2010), 2011 data from Forsch (unpublished).
Lower case letters indicate significant differences between treatments within years at $p < 0.05$.
Upper case letters indicate significant differences between years within treatments at $p < 0.05$.

Table 2.18. Mean Smith Wilson evenness and Shannon index of diversity at Aurora in the first five years after reclamation.

			Smith Wilson evenness		Shannon index of diversity	
Year	Cover soil	Application depth (cm)	Sand	Peat-sand	Sand	Peat-sand
2006	LFH mineral soil mix	10	0.2 (0.0)^{B}	0.2 (0.0)^{B}	1.3 (0.2)^{B}	2.1 (0.3)^{B}
	LFH mineral soil mix	20	0.1 (0.0)^{B}	0.2 (0.0)^{B}	1.6 (0.0)^{B}	1.9 (0.3)^{B}
	Peat mineral soil mix	-		0.2 (0.0)^{B}		1.4 (0.1)^{B}
2007	LFH mineral soil mix	10	0.2 (0.0)^{B}	0.1 (0.0)^{B}	1.8 (0.1)^{AB}	2.0 (0.1)^{AB}
	LFH mineral soil mix	20	0.2 (0.0)^{B}	0.2 (0.1)^{B}	2.0 (0.3)^{AB}	2.0 (0.3)^{AB}
	Peat mineral soil mix	-		0.2 (0.1)^{B}		2.1 (0.1)^{AB}
2008	LFH mineral soil mix	10	0.2 (0.0)^{B}	0.2 (0.0)^{B}	2.1 (0.1)^{A}	2.2 (0.0)^{A}
	LFH mineral soil mix	20	0.2 (0.1)^{B}	0.1 (0.0)^{B}	2.2 (0.2)^{A}	2.1 (0.1)^{A}
	Peat mineral soil mix	-		0.2 (0.0)^{B}		1.7 (0.3)^{A}
2010	LFH mineral soil mix	10	0.1 (0.0)^{A}	0.1 (0.0)^{A}	2.2 (0.1)^{AB}	2.1 (0.2)^{AB}
	LFH mineral soil mix	20	0.1 (0.0)^{A}	0.1 (0.0)^{A}	1.9 (0.1)^{AB}	1.9 (0.2)^{AB}
	Peat mineral soil mix	-		0.1 (0.0)^{A}		1.7 (0.3)^{AB}

Numbers are means with standard errors in brackets, n = 3.
2006, 2007, 2008 data from Mackenzie (2012a).
There were no significant differences between treatment combinations within years at $p < 0.05$.
Upper case letters indicate significant differences between years within treatment combinations at $p < 0.05$.

Table 2.19. Mean Smith-Wilson evenness and Shannon index of diversity at W1 dump in the first seven years after reclamation.

		Smith Wilson evenness		Shannon index of diversity	
Year	Application depth (cm)	LFH mineral soil mix	Peat mineral soil mix	LFH mineral soil mix	Peat mineral soil mix
2004	10	0.2 (0.0)	0.1 (0.0)	2.0 (0.3)$^{a/AB}$	0.9 (0.3)$^{b/C}$
	20	0.2 (0.0)	0.3 (0.2)	2.1 (0.1)$^{a/AB}$	1.2 (0.3)$^{b/C}$
2005	10	0.2 (0.1)	0.1 (0.0)	2.6 (0.1)$^{a/A}$	2.2 (0.1)$^{b/B}$
	20	0.2 (0.0)	0.2 (0.1)	2.4 (0.1)$^{a/A}$	2.3 (0.1)$^{b/B}$
2006	10	0.1 (0.0)	0.2 (0.0)	2.6 (0.0)^{A}	2.7 (0.1)^{A}
	20	0.1 (0.0)	0.1 (0.0)	2.5 (0.2)^{A}	2.5 (0.1)^{A}
2010	10	0.1 (0.0)	0.2 (0.0)	2.2 (0.2)^{B}	2.3 (0.1)^{AB}
	20	0.1 (0.0)	0.1 (0.0)	2.3 (0.0)^{B}	2.5 (0.1)^{AB}

Numbers are means with standard errors in brackets, n = 3.
2004, 2005, 2006 data from Mackenzie (2006), Mackenzie (unpublished).
Lower case letters indicate significant differences between treatment combinations within years at $p < 0.05$.
Upper case letters indicate significant differences between years within treatment combinations at $p < 0.05$.

Table 2.20. Mean Smith Wilson evenness and Shannon index of diversity at MLSB thirteen years after reclamation.

Site	Cover soil	Application depth (cm)	Application season	Smith Wilson evenness	Shannon index of diversity
Cell 16	LFH mineral soil mix	18	Winter	0.1	2.2
	Peat mineral soil mix	18	Unknown	0.0	1.7
Cell 18	LFH mineral soil mix	12	Winter	0.1 (0.0)	2.3 (0.1)
	LFH mineral soil mix	12	Summer	0.1 (0.0)	2.2 (0.1)
	Peat mineral soil mix	18	Unknown	0.1 (0.1)	2.3 (0.3)

Numbers are means with standard errors in brackets, n = 1 at Cell 16, n = 3 for LFH mineral soil mix at Cell 18, n = 2 for peat mineral soil mix at Cell 18.
There were no significant differences due to cover soil effects at $p < 0.05$.

Table 2.21. Mean total, native and non-native cover at SE dump in the first four years after reclamation.

	Total cover (%)		Native cover (%)		Non-native cover (%)	
Year	LFH mineral soil mix	Peat mineral soil mix	LFH mineral soil mix	Peat mineral soil mix	LFH mineral soil mix	Peat mineral soil mix
2008	11.3 (4.6)^{B}	4.3 (3.7)^{C}	6.9 (2.8)^{B}	2.1 (1.7)^{C}	4.5 (2.0)	2.2 (2.0)^{C}
2009	77.8 (2.6)$^{a/A}$	40.6 (4.8)$^{b/B}$	66.9 (2.9)$^{a/A}$	22.2 (5.2)$^{b/B}$	10.8 (0.8)^{b}	18.3 (2.4)$^{a/A}$
2010	62.7 (4.7)^{A}	69.7 (6.1)^{A}	52.3 (3.8)^{A}	45.2 (3.0)^{A}	10.3 (2.1)^{b}	24.5 (4.8)$^{a/A}$
2011	64.7 (6.8)$^{a/A}$	48.8 (6.1)$^{b/B}$	59.2 (6.5)$^{a/A}$	38.2 (6.7)$^{b/AB}$	5.5 (0.8)^{b}	10.6 (1.2)$^{a/B}$

Numbers are means with standard errors in brackets, n = 6.
2008 and 2009 data from Brown (2010), 2011 data from Forsch (unpublished).
Lower case letters indicate significant differences between treatment combinations within years at $p < 0.05$.
Upper case letters indicate significant differences between years within treatment combinations at $p < 0.05$.

Table 2.22. Mean total, native species and non-native species cover at Aurora in the first five years after reclamation.

			Total cover (%)		Native cover (%)		Non-native cover (%)	
Year	Cover soil	Application depth (cm)	Sand	Peat-sand	Sand	Peat-sand	Sand	Peat-sand
2006	LFH	10	4.3 (1.1)$^{ab/B}$	1.2 (0.7)$^{bc/B}$	4.3 (1.0)$^{a/B}$	1.2 (0.7)$^{bc/B}$	0.0 (0.0/0.2))^{ab}	0.0 (0.0/0.1)^{ab}
	LFH	20	4.2 (0.9)$^{a/C}$	1.4 (0.5)$^{abc/C}$	4.2 (0.9)$^{ab/C}$	1.4 (0.5)$^{abc/C}$	0.0 (0.0/0.0)$^{b/B}$	0.0 (0.0/0.0)^{ab}
	Peat	-		0.6 (0.2)^{c}		0.4 (0.1)^{c}		0.1 (0.1/0.3)$^{a/B}$
2007	LFH	10	9.0 (0.7)^{AB}	10.2 (2.0)^{A}	8.8 (0.8)$^{ab/AB}$	9.7 (1.9)$^{ab/AB}$	0.2 (0.1/0.4)	0.3 (0.2/0.8)
	LFH	20	15.8 (3.7)^{B}	10.8 (5.3)^{B}	15.6 (3.7)$^{a/B}$	10.7 (5.3)$^{ab/B}$	0.1 (0.1/0.2)^{A}	0.2 (0.0/0.2)
	Peat	-		1.7 (0.3)		1.6 (0.3)^{b}		0.1 (0.0/0.2)^{B}
2008	LFH	10	18.7 (3.7)$^{ab/A}$	20.5 (3.0)$^{ab/A}$	17.5 (3.7)$^{ab/A}$	18.3 (2.7)$^{ab/A}$	1.3 (0.4/1.9)	2.3 (1.6/2.6)
	LFH	20	23.5 (3.4)$^{ab/B}$	32.3 (7.5)$^{a/A}$	22.5 (3.0)$^{ab/B}$	30.0 (7.0)$^{a/A}$	0.5 (0.4/1.9)^{A}	2.3 (1.2/3.3)
	Peat	-		7.3 (1.3)^{b}		6.4 (1.3)^{b}		0.9 (0.7/1.1)^{B}
2010	LFH	10	24.6 (2.2)$^{bc/AB}$	33.6 (10.7)$^{abc/A}$	24.6 (2.2)$^{bc/AB}$	32.9 (10.4)$^{abc/A}$	0.0 (0.0/0.0)	0.7 (0.3/1.0)
	LFH	20	61.6 (9.5)$^{a/A}$	55.2 (13.0)$^{ab/A}$	61.6 (9.5)$^{a/A}$	55.1 (13.0)$^{ab/A}$	0.0 (0.0/0.0)^{AB}	0.0 (0.0/0.1)
	Peat	-		10.8 (1.6)^{c}		6.1 (2.0)^{c}		4.1 (3.0/7.0)^{A}

LFH refers to LFH mineral soil mix, peat refers to peat mineral soil mix.
Numbers are means with standard errors in brackets for normal data, medians with 5th/95th percentiles for non-normal data, n = 3.
2006, 2007, 2008 data from Mackenzie (2012a).
Lower case letters indicate significant differences between treatment combinations within years at $p < 0.05$.
Upper case letters indicate significant differences between years within treatment combinations at $p < 0.05$.

Table 2.23. Mean total, native and non-native cover at W1 dump in the first seven years after reclamation.

		Total cover (%)		Native cover (%)		Non-native cover (%)	
Year	Application depth (cm)	LFH mineral soil mix	Peat mineral soil mix	LFH mineral soil mix	Peat mineral soil mix	LFH mineral soil mix	Peat mineral soil mix
2004	10	1.1 (0.8/1.2)$^{b/C}$	0.3 (0.1/0.4)$^{c/C}$	0.9 (0.2)$^{b/D}$	0.2 (0.1)$^{b/C}$	0.1 (0.1)$^{b/B}$	0.1 (0.1)$^{b/B}$
	20	3.8 (2.0/3.9)$^{a/C}$	0.1 (0.0/0.2)$^{c/C}$	2.1 (0.5)$^{a/C}$	0.1 (0.0)$^{b/C}$	1.0 (0.3)$^{a/B}$	0.0 (0.0)$^{b/B}$
2005	10	21.2 (18.7/21.7)$^{b/B}$	5.9 (5.7/6.5)$^{c/B}$	15.7 (1.3)$^{b/C}$	3.7 (0.8)$^{c/C}$	4.7 (0.7)$^{b/A}$	2.4 (0.7)$^{b/B}$
	20	35.7 (34.8/37.7)$^{a/B}$	4.9 (4.7/5.5)$^{c/B}$	24.1 (2.2)$^{a/B}$	3.7 (0.5)$^{c/C}$	11.9 (1.5)$^{a/A}$	1.3 (0.5)$^{b/B}$
2006	10	46.3 (41.0/49.2)$^{b/A}$	34.6 (33.2/37.9)$^{c/A}$	37.1 (4.1)$^{b/B}$	26.6 (2.4)$^{bc/B}$	6.8 (2.0)^{A}	4.9 (1.4)^{A}
	20	69.7 (65.4/72.7)$^{a/A}$	21.4 (19.3/43.2)$^{c/A}$	56.9 (2.8)$^{a/A}$	21.3 (6.6)$^{b/B}$	9.9 (2.0)^{A}	3.8 (0.5)^{A}
2010	10	59.8 (58.8/60.1)^{A}	41.5 (40.0/65.9)^{A}	53.4 (1.9)^{A}	39.6 (8.1)^{A}	6.1 (2.1)$^{ab/A}$	10.1 (1.5)$^{a/A}$
	20	60.9 (56.9/68.0)^{A}	51.7 (47.1/56.2)^{A}	57.3 (3.7)^{A}	43.7 (2.5)^{A}	4.7 (0.1)$^{b/B}$	7.9 (0.6)$^{ab/A}$

Numbers are means with standard errors in brackets for normal data, medians with 5th/95th percentiles for non-normal data, n = 3.
2004, 2005, 2006 data from Mackenzie (2006), Mackenzie (unpublished).
Lower case letters indicate significant differences between treatment combinations within years at $p < 0.05$.
Upper case letters indicate significant differences between years within treatment combinations at $p < 0.05$.

Table 2.24. Mean total, native and non-native cover at MLSB thirteen years after reclamation.

Site	Cover soil	Application depth (cm)	Application season	Total cover (%)	Native cover (%)	Non-native cover (%)
Cell 16	LFH mineral soil mix	18	Winter	47.1	41.7	5.3
	Peat mineral soil mix	18	Unknown	28.6	3.0	25.6
Cell 18	LFH mineral soil mix	12	Winter	83.8 (66.6/83.9)	73.6 (7.7)[a]	3.9 (1.5)[b]
	LFH mineral soil mix	12	Summer	78.4 (68.8/80.0)	71.3 (4.2)[a]	4.5 (1.0)[b]
	Peat mineral soil mix	18	Unknown	40.2 (37.4/43.0)	19.0 (5.8)[b]	21.2 (2.8)[a]

Numbers are means with standard errors in brackets for normal data, medians with $5^{th}/95^{th}$ percentiles in brackets for non-normal data, n = 1 at Cell 16, n = 3 for LFH mineral soil mix at Cell 18, n = 2 for peat mineral soil mix at Cell 18.
Lower case letters indicate significant differences between treatments at $p < 0.05$ for parametric testing and $p < 0.1$ for non-parametric testing.

Table 2.25. Cumulative effect size and confidence interval from meta analysis of comparing LFH mineral soil mix and peat mineral soil mix.

Parameter	Year	Cumulative effect size	Confidence interval
Woody plant density	1	2.9799	2.1983 to 4.4485
	2	4.9333	2.3985 to 7.8616
	3	2.8549	1.1895 to 5.3046
	Final	8.8932	2.1848 to 24.8422
Species richness	1	6.2319	2.7648 to 12.0223
	2	2.7007	2.1103 to 3.5782
	3	1.7327	1.1208 to 2.2634
	Final	0.7402	0.2276 to 1.4210
Native species richness	1	4.9738	2.8354 to 7.6783
	2	2.5727	2.2227 to 3.1293
	3	2.4230	1.7237 to 3.4697
	Final	1.2142	0.6721 to 1.8321
Evenness	1	0.1669	-0.6091 to 0.9350
	2	-0.5869	-1.0229 to -0.0005
	3	-0.2743	-0.9017 to 0.3166
	Final	-0.2976	-0.6935 to 0.1860
Diversity	1	1.2454	0.5775 to 1.7190
	2	0.2599	-0.4830 to 1.2775
	3	0.2216	-0.6485 to 0.7894
	Final	-0.0100	-0.4949 to 0.3479
Total cover	1	1.8072	1.0331 to 2.5305
	2	6.5503	3.0048 to 12.1626
	3	1.9624	0.9843 to 2.6490
	Final	2.2068	1.5022 to 2.9877
Native cover	1	1.7493	1.1268 to 2.3853
	2	3.8776	2.6416 to 5.0844
	3	2.2957	1.5367 to 3.0280
	Final	2.6617	1.8862 to 3.6250
Non-native cover	1	-0.1805	-0.8954 to 0.6803
	2	0.9795	-0.0840 to 2.3300
	3	0.3368	-0.4626 to 1.1538
	Final	-2.5910	-3.3694 to -2.0541

Years 1, 2 and 3 represent the first, second and third years after soil placement; final represents the final year of sampling which occurred at different ages for each site.

Table 2.26. Mean cover of growth forms at SE dump in the first four years after reclamation.

Year	Growth form	Cover (%) LFH mineral soil mix		Cover (%) Peat mineral soil mix	
2008	Grass	0.5 (0.3)		0.0 (0.0)	
	Sedge	0.1 (0.1)		0.0 (0.0)	
	Forb	10.5 (4.4)		4.1 (3.7)	
	Pteridophyte	0.0 (0.0)		0.0 (0.0)	
	Moss	0.1 (0.0)		0.1 (0.1)	
	Shrub	0.2 (0.0)		0.0 (0.0)	
	Tree	0.0 (0.0)		0.0 (0.0)	
	Total	11.3 (4.6)		4.3 (3.7)	
2009	Grass	9.2 (2.9)		1.7 (0.8)	
	Sedge	6.4 (2.2)		0.8 (0.2)	
	Forb	39.8 (2.4)		29.9 (3.0)	
	Pteridophyte	0.1 (0.1)	a	1.7 (0.7)	b
	Moss	17.8 (4.0)		5.4 (2.1)	
	Shrub	4.3 (1.1)		1.0 (0.5)	
	Tree	0.1 (0.1)		0.0 (0.0)	
	Total	77.8 (2.6)		40.6 (4.8)	
2010	Grass	15.3 (3.8)		5.9 (1.5)	
	Sedge	2.6 (0.8)		0.9 (0.4)	
	Forb	33.0 (4.7)		45.0 (5.1)	
	Pteridophyte	0.0 (0.0)	a	3.4 (1.5)	b
	Moss	1.1 (0.4)		9.9 (2.4)	
	Shrub	10.2 (2.0)		4.4 (2.7)	
	Tree	0.3 (0.3)		0.3 (0.2)	
	Total	62.7 (4.7)		69.7 (6.1)	
2011	Grass	10.9 (1.5)		3.9 (1.1)	
	Sedge	2.8 (0.4)		1.0 (0.5)	
	Forb	23.3 (1.6)		24.8 (1.2)	
	Pteridophyte	0.0 (0.0)	a	1.2 (0.9)	b
	Moss	1.1 (0.5)		10.9 (2.6)	
	Shrub	26.3 (9.1)		6.7 (2.3)	
	Tree	0.3 (0.3)		0.4 (0.4)	
	Total	64.7 (6.8)		48.8 (6.1)	

Numbers are means with standard errors in brackets, n = 6.
2008, 2009 data from Brown (2010), 2011 data from Forsch (unpublished).
Lower case letters indicate significant differences between treatments within years at $p < 0.05$.

Table 2.27. Mean cover of growth forms at Aurora in the first five years after reclamation.

		Cover (%)				
		LFH mineral soil mix				Peat mineral soil mix
		Sand		Peat-sand		
Year	Growth form	10 cm	20 cm	10 cm	20 cm	
2006	Grass	0.2 (0.1)	0.1 (0.0)	0.1 (0.1)	0.2 (0.1)	0.1 (0.0)
	Sedge	0.1 (0.1)	0.1 (0.0)	0.1 (0.0)	0.0 (0.0)	0.0 (0.0)
	Forb	3.3 (0.8)	3.1 (0.8)	1.0 (0.6)	0.7 (0.4)	0.5 (0.1)
	Pteridophyte	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
	Moss/Lichen	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
	Shrub	0.6 (0.3)	0.8 (0.2)	0.1 (0.1)	0.4 (0.2)	0.0 (0.0)
	Tree	0.1 (0.0)	0.1 (0.0)	0.0 (0.0)	0.1 (0.0)	0.0 (0.0)
	Total	4.3 (1.1)	4.2 (0.9)	1.2 (0.7)	1.4 (0.5)	0.6 (0.1)
2007	Grass	1.3 (0.3)	1.7 (0.4)	1.0 (0.2)	1.6 (0.8)	0.4 (0.1)
	Sedge	0.3 (0.1)	0.7 (0.3)	0.6 (0.0)	0.3 (0.1)	0.2 (0.1)
	Forb	6.5 (0.8)	11.0 (2.5)	7.4 (1.8)	7.6 (3.8)	1.1 (0.2)
	Pteridophyte	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
	Moss/Lichen	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
	Shrub	1.0 (0.1)	2.1 (0.6)	1.2 (0.2)	1.3 (0.7)	0.0 (0.0)
	Tree	0.0 (0.0)	0.3 (0.1)	0.0 (0.0)	0.1 (0.0)	0.1 (0.0)
	Total	9.0 (0.7)	15.8 (3.7)	10.2 (2.0)	10.8 (5.3)	1.7 (0.3)

Numbers are means with standard errors in brackets, n = 3.
2006, 2007, 2008 data from Mackenzie (2012a).
Lower case letters indicate significant differences between treatment combinations within years at $p < 0.05$.

Table 2.27. Mean cover of growth forms at Aurora in the first five years after reclamation (continued).

		Cover (%)				
		LFH mineral soil mix				Peat mineral soil mix
		Sand		Peat-sand		
Year	Growth form	10 cm	20 cm	10 cm	20 cm	
2008	Grass	3.7 (1.2)	3.8 (0.6)	3.0 (1.2)	6.5 (3.0)	3.2 (2.0)
	Sedge	0.8 (0.2)	1.5 (1.0)	1.7 (0.1)	2.0 (0.7)	0.7 (0.3)
	Forb	11.5 (3.1)	12.6 (1.1)	12.7 (1.5)	19.6 (4.7)	2.6 (0.7)
	Pteridophyte	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
	Moss/Lichen	0.0 (0.0)	0.0 (0.0)	0.1 (0.1)	0.0 (0.0)	0.0 (0.0)
	Shrub	2.2 (0.8)	5.3 (1.2)	2.9 (1.1)	4.1 (0.6)	0.7 (0.5)
	Tree	0.4 (0.0)	0.4 (0.0)	0.1 (0.1)	0.1 (0.0)	0.0 (0.0)
	Total	18.7 (3.7)	23.5 (3.4)	20.5 (3.0)	32.3 (7.5)	7.3 (1.3)
2010	Grass	2.9 (1.5)	4.9 (0.8)	3.6 (0.8)	6.0 (0.8)	1.5 (0.7)
	Sedge	0.7 (0.2)	2.8 (0.1)	2.3 (0.8)	2.1 (0.4)	0.9 (0.3)
	Forb	11.2 (1.2)	23.2 (5.1)	11.8 (4.0)	22.6 (10.2)	7.1 (1.0)
	Pteridophyte	0.0 (0.0) ab	0.0 (0.0) a	0.0 (0.0) ab	0.0 (0.0) ab	0.0 (0.0) b
	Moss/Lichen	4.8 (0.8)	23.2 (6.4)	9.6 (6.7)	15.0 (6.2)	0.5 (0.6)
	Shrub	3.9 (0.6)	5.9 (1.4)	5.6 (3.7)	9.3 (3.7)	0.5 (0.3)
	Tree	1.1 (0.4)	1.6 (1.1)	0.5 (0.5)	0.2 (0.2)	0.2 (0.1)
	Total	24.6 (2.2)	61.6 (9.5)	33.6 (10.7)	55.2 (13.0)	10.8 (1.6)

Numbers are means with standard errors in brackets, n = 3.
2006, 2007, 2008 data from Mackenzie (2012a).
Lower case letters indicate significant differences between treatment combinations within years at $p < 0.05$.

Table 2.28. Mean cover of growth forms at W1 dump in the first seven years after reclamation.

		Cover (%)							
		LFH mineral soil mix				Peat mineral soil mix			
Year	Growth form	10 cm		20 cm		10 cm		20 cm	
2004	Grass	0.0 (0.0)		0.1 (0.1)		0.0 (0.0)		0.0 (0.0)	
	Sedge	0.0 (0.0)		0.2 (0.2)		0.0 (0.0)		0.0 (0.0)	
	Rush	0.0 (0.0)		0.0 (0.0)		0.0 (0.0)		0.0 (0.0)	
	Forb	0.8 (0.1)		2.4 (0.5)		0.2 (0.1)		0.0 (0.0)	
	Pteridophyte	0.0 (0.0)		0.0 (0.0)		0.0 (0.0)		0.0 (0.0)	
	Moss	0.0 (0.0)		0.0 (0.0)		0.0 (0.0)		0.0 (0.0)	
	Shrub	0.1 (0.0)		0.4 (0.1)		0.1 (0.1)		0.1 (0.0)	
	Tree	0.1 (0.0)		0.0 (0.0)		0.0 (0.0)		0.0 (0.0)	
	Total	1.0 (0.1)		3.1 (0.7)		0.3 (0.1)		0.1 (0.0)	
2005	Grass	1.6 (0.3)		2.6 (0.1)		0.4 (0.1)		0.5 (0.1)	
	Sedge	0.6 (0.2)		1.1 (0.3)		0.4 (0.2)		0.5 (0.0)	
	Rush	0.0 (0.0)		0.0 (0.0)		0.0 (0.0)		0.0 (0.0)	
	Forb	16.6 (1.4)	a	28.8 (0.4)	b	4.3 (0.4)	c	3.3 (0.1)	c
	Pteridophyte	0.2 (0.1)		0.1 (0.1)		0.6 (0.1)		0.6 (0.1)	
	Moss	0.4 (0.4)		0.4 (0.2)		0.0 (0.0)		0.0 (0.0)	
	Shrub	1.0 (0.1)		2.8 (0.5)		0.5 (0.2)		0.1 (0.1)	
	Tree	0.0 (0.0)		0.2 (0.1)		0.0 (0.0)		0.0 (0.0)	
	Total	20.5 (1.0)		36.1 (0.9)		6.1 (0.3)		5.0 (0.3)	

Numbers are means with standard errors in brackets, n = 3.
2004, 2005, 2006 data from Mackenzie (2006), Mackenzie (unpublished).
Lower case letters indicate significant differences between treatment combinations within years at $p < 0.05$.

Table 2.28. Mean cover of growth forms at W1 dump in the first seven years after reclamation (continued).

		Cover (%)							
		LFH mineral soil mix				Peat mineral soil mix			
Year	Growth form	10 cm		20 cm		10 cm		20 cm	
2006	Grass	3.3 (0.8)		6.0 (0.6)		3.7 (0.6)		3.2 (0.6)	
	Sedge	1.5 (0.5)		2.0 (0.3)		2.9 (0.8)		4.0 (2.0)	
	Rush	0.0 (0.0)		0.0 (0.0)		0.0 (0.0)		0.0 (0.0)	
	Forb	30.5 (0.6)		38.4 (1.8)		18.8 (0.5)		14.7 (3.9)	
	Pteridophyte	0.4 (0.2)		0.5 (0.2)		3.5 (0.6)		1.5 (0.2)	
	Moss	4.4 (1.6)		12.2 (2.4)		0.9 (0.3)		0.6 (0.3)	
	Shrub	3.5 (1.2)		7.4 (1.5)		1.5 (0.2)		0.8 (0.1)	
	Tree	0.4 (0.2)		0.3 (0.2)		0.1 (0.0)		0.3 (0.1)	
	Total	45.4 (2.7)		69.2 (2.4)		35.3 (1.6)		28.7 (8.5)	
2010	Grass	0.9 (0.4)		2.6 (0.9)		1.1 (0.3)		1.4 (0.3)	
	Sedge	0.5 (0.1)		0.8 (0.3)		0.8 (0.3)		1.6 (0.3)	
	Rush	0.0 (0.0)		0.0 (0.0)		0.0 (0.0)		0.0 (0.0)	
	Forb	39.1 (2.9)	a	40.1 (2.1)	a	22.8 (3.3)	b	24.2 (1.4)	b
	Pteridophyte	4.9 (1.0)		4.2 (0.5)		11.0 (3.3)		11.0 (1.7)	
	Moss	6.8 (2.7)		5.8 (1.0)		8.6 (1.4)		4.1 (0.6)	
	Shrub	4.7 (2.6)		7.4 (2.0)		4.3 (3.5)		6.1 (1.7)	
	Tree	2.5 (1.2)		1.1 (0.4)		1.0 (0.8)		3.2 (2.0)	
	Total	59.6 (0.4)		62.0 (3.6)		50.0 (9.3)		51.7 (2.9)	

Numbers are means with standard errors in brackets, n = 3.
2004, 2005, 2006 data from Mackenzie (2006), Mackenzie (unpublished).
Lower case letters indicate significant differences between treatments combinations within years at $p < 0.05$.

Table 2.29. Mean cover of various growth forms at MLSB thirteen years after reclamation.

	Cover (%)				
Site	Cell 16		Cell 18		
Cover soil	LFH mineral soil mix	Peat mineral soil mix	LFH mineral soil mix		Peat mineral soil mix
Application season	Winter	Unknown	Winter	Summer	Unknown
Grass	5.1	2.4	4.4 (1.4)	3.8 (0.8)	6.3 (2.6)
Sedge	1.5	0.0	1.3 (1.0)	1.4 (0.6)	0.1 (0.1)
Forb	21.8	24.5	39.6 (1.8)	43.6 (4.9)	27.7 (2.3)
Pteridophyte	0.0	0.0	0.0 (0.0/0.04)	0.0 (0.0/0.0)	0.0 (0.0/0.0)
Moss/Lichen	1.4	0.7	0.9 (0.4)	2.3 (0.9)	2.1 (1.6)
Shrub	11.3	1.0	30.7 (5.7)[a]	24.6 (4.1)[b]	1.4 (1.0)[b]
Tree	5.8	0.0	0.4 (0.1/1.2)[a]	0.0 (0.0/0.3)[b]	2.6 (2.4/2.9)[a]
Total	47.1	28.6	83.8 (66.6/83.9)[a]	78.4 (68.8/80.0)[a]	40.2 (37.4/43.0)[a]

Numbers are means with standard errors in brackets for normal data, medians with $5^{th}/95^{th}$ percentiles in brackets for non-normal data, n = 1 at Cell 16, n = 3 for LFH mineral soil mix at Cell 18, n = 2 for peat mineral soil mix at Cell 18.
Lower case letters indicate significant differences between treatments at $p < 0.05$ for parametric testing and $p < 0.1$ for non-parametric testing.

Table 2.30. Dominant species on SE dump in the first year after reclamation.

Cover soil	Total cover (%)	Dominant species	CSR type	Cover (%)	Subdominant species	CSR type	Cover (%)
LFH mineral soil mix	11.3 (4.6)	*Crepis tectorum*	CR	3.1 (1.5)	*Potentilla norvegica*	C/CR	2.5 (1.1)
					Achillea millefolium	CR/CSR	1.4 (0.8)
					Sonchus arvensis	CR	0.8 (0.3)
					Chenopodium capitatum	R/CR	0.8 (0.4)
Peat mineral soil mix	4.3 (3.7)	*Potentilla norvegica*	C/CR	1.5 (1.5)	*Chenopodium album*	R/CR	1.1 (1.0)
					Sonchus arvensis	CR	0.7 (0.6)
					Crepis tectorum	CR	0.4 (0.4)

Numbers are means with standard errors in brackets, n = 6.
2008, 2009 data from Brown (2010), 2011 data from Forsch (unpublished).

Table 2.31. Dominant species on SE dump in the second year after reclamation.

Cover soil	Total cover (%)	Dominant species	CSR type	Cover (%)	Subdominant species	CSR type	Cover (%)
LFH mineral soil mix	77.8 (2.6)	Moss spp.	-	17.8 (4.0)	*Potentilla norvegica*	C/CR	8.6 (2.2)
					Achillea millefolium	CR/CSR	8.4 (2.9)
					Carex spp.	-	6.4 (2.2)
					Crepis tectorum	CR	6.4 (0.9)
					Geranium bicknellii	SC	4.3 (2.2)
Peat mineral soil mix	40.6 (4.8)	*Chenopodium album*	R/CR	9.8 (3.3)	Moss spp.	-	5.4 (2.1)
					Epilobium angustifolium	C	4.0 (1.5)
					Crepis tectorum	CR	3.8 (1.0)
					Sonchus arvensis	CR	3.8 (1.3)
					Potentilla norvegica	C/CR	3.0 (1.6)

Numbers are means with standard errors in brackets, n = 6.
2008, 2009 data from Brown (2010), 2011 data from Forsch (unpublished).

Table 2.32. Dominant species on SE dump in the third year after reclamation.

Cover soil	Total cover (%)	Dominant species	CSR type	Cover (%)	Subdominant species	CSR type	Cover (%)
LFH mineral soil mix	62.7 (4.7)	*Rubus idaeus*	SC	9.5 (1.8)	*Sonchus arvensis*	CR	7.9 (2.2)
					Achillea millefolium	CR/CSR	7.7 (1.8)
					Agrostis scabra	-	6.6 (2.0)
					Poa palustris	CSR	3.9 (2.4)
					Epilobium angustifolium	C	3.7 (1.2)
					Aster ciliolatus	C	3.2 (1.4)
Peat mineral soil mix	69.7 (6.1)	*Sonchus arvensis*	CR	10.7 (0.8)	Moss spp.	-	9.9 (2.4)
					Crepis tectorum	CR	8.7 (4.1)
					Epilobium angustifolium	C	7.7 (1.8)
					Rubus idaeus	SC	4.1 (2.7)
					Achillea millefolium	CR/CSR	4.0 (1.5)

Numbers are means with standard errors in brackets, n = 6.
2008, 2009 data from Brown (2010), 2011 data from Forsch (unpublished).

Table 2.33. Dominant species on SE dump in the fourth year after reclamation.

Cover soil	Total cover (%)	Dominant species	CSR type	Cover (%)	Subdominant species	CSR type	Cover (%)
LFH mineral soil mix	64.7 (6.8)	*Rubus idaeus*	SC	23.9 (8.1)	*Epilobium angustifolium*	C	5.6 (1.3)
					Sonchus arvensis	CR	4.8 (0.7)
					Fragaria virginiana	C/SC or SC	3.9 (0.8)
Peat mineral soil mix	48.8 (6.1)	Moss spp.	-	10.9 (2.6)	*Sonchus arvensis*	CR	7.8 (0.9)
					Epilobium angustifolium	C	6.5 (1.4)
					Rubus idaeus	SC	5.7 (2.5)
					Fragaria virginiana	C/SC or SC	3.0 (2.0)

Numbers are means with standard errors in brackets, n = 6.
2008, 2009 data from Brown (2010), 2011 data from Forsch (unpublished).

Table 2.34. Dominant species at Aurora in the first year after reclamation.

Cover soil	Substrate	Application depth (cm)	Total cover (%)	Dominant species	C-S-R type	Cover (%)	Subdominant species	C-S-R type	Cover (%)
LFH	Sand	10	4.3 (1.1)	*Epilobium angustifolium*	C	3.0 (0.8)	*Rosa acicularis*	C or C/CR	0.3 (0.2)
							Elymus innovatus	C/CSR	0.2 (0.1)
LFH	Sand	20	4.2 (0.9)	*Epilobium angustifolium*	C	2.5 (0.6)	*Rosa acicularis*	C or C/CR	0.5 (0.2)
LFH	Peat-sand	10	1.2 (0.7)	*Epilobium angustifolium*	C	0.6 (0.4)	*Lathyrus venosus*	C or C/CR	0.2 (0.1)
LFH	Peat-sand	20	1.4 (0.5)	*Epilobium angustifolium*	C	0.5 (0.4)	*Rosa acicularis*	C or C/CR	0.3 (0.2)
							Elymus innovatus	C/CSR	0.1 (0.1)
Peat	Peat-sand	-	0.6 (0.1)	*Epilobium angustifolium*	C	0.2 (0.1)	*Chenopodium album*	R/CR	0.2 (0.1)
							Agropyron trachycaulum	C	0.1 (0.0)
							Urtica dioica	C	0.1 (0.0)

LFH refers to LFH mineral soil mix, peat refers to peat mineral soil mix.
Numbers are means with standard errors in brackets, n = 3.
2006, 2007, 2008 data from Mackenzie (2012a).

Table 2.35. Dominant species at Aurora in the second year after reclamation.

Cover soil	Substrate	Application depth (cm)	Total cover (%)	Dominant species	C-S-R type	Cover (%)	Subdominant species	C-S-R type	Cover (%)
LFH	Sand	10	9.0 (0.7)	*Epilobium angustifolium*	C	4.8 (0.6)	*Elymus innovatus*	C/CSR	0.8 (0.2)
							Fragaria virginiana	C/SC or SC	0.7 (0.4)
							Rosa acicularis	C or C/CR	0.5 (0.1)
LFH	Sand	20	15.8 (3.7)	*Epilobium angustifolium*	C	7.8 (2.5)	*Rosa acicularis*	C or C/CR	1.0 (0.6)
							Fragaria virginiana	C/SC or SC	1.0 (0.5)
							Elymus innovatus	C/CSR	0.9 (0.3)
LFH	Peat-sand	10	10.2 (2.0)	*Epilobium angustifolium*	C	5.0 (1.3)	*Geranium bicknellii*	SC	0.9 (0.2)
							Rosa acicularis	C or C/CR	0.7 (0.3)
							Lathyrus venosus	C or C/CR	0.6 (0.2)
LFH	Peat-sand	20	10.8 (5.3)	*Epilobium angustifolium*	C	5.8 (3.6)	*Elymus innovatus*	C/CSR	1.3 (0.8)
Peat	Peat-sand	-	1.7 (0.3)	*Epilobium angustifolium*	C	0.5 (0.1)	*Urtica dioica*	C	0.3 (0.1)
							Calamagrostis Canadensis	C/CSR	0.2 (0.1)
							Carex spp.	-	0.2 (0.1)
							Agropyron trachycaulum	C	0.1 (0.1)

LFH refers to LFH mineral soil mix, peat refers to peat mineral soil mix.
Numbers are means with standard errors in brackets, n = 3.
2006, 2007, 2008 data from Mackenzie (2012a).

Table 2.36. Dominant species at Aurora in the third year after reclamation.

Cover soil	Substrate	Application depth (cm)	Total cover (%)	Dominant species	C-S-R type	Cover (%)	Subdominant species	C-S-R type	Cover (%)
LFH	Sand	10	18.7 (3.7)	*Epilobium angustifolium*	C	6.4 (0.7)	*Fragaria virginiana*	C/SC or SC	2.6 (2.2)
							Elymus innovatus	C/CSR	2.2 (1.3)
							Crepis tectorum	CR	1.2 (0.4)
LFH	Sand	20	23.5 (3.4)	*Epilobium angustifolium*	C	7.4 (1.1)	*Rosa acicularis*	C or C/CR	2.9 (1.2)
							Fragaria virginiana	C/SC or SC	2.4 (1.3)
							Elymus innovatus	C/CSR	2.2 (0.6)
LFH	Peat-sand	10	20.5 (3.0)	*Epilobium angustifolium*	C	8.2 (1.0)	*Elymus innovatus*	C/CSR	2.0 (1.3)
							Crepis tectorum	CR	1.8 (0.3)
							Rosa acicularis	C or C/CR	1.4 (0.5)
LFH	Peat-sand	20	32.3 (7.5)	*Epilobium angustifolium*	C	11.8 (2.7)	*Elymus innovatus*	C/CSR	5.4 (3.0)
							Fragaria virginiana	C/SC or SC	2.5 (2.3)
							Crepis tectorum	CR	2.2 (0.7)
							Rosa acicularis	C or C/CR	2.1 (0.1)
Peat	Peat-sand	-	7.3 (1.3)	*Calamagrostis canadensis*	C/CSR	3.0 (1.9)	*Epilobium angustifolium*	C	1.0 (0.5)
							Salix spp.	-	0.7 (0.5)
							Urtica dioica	C	0.6 (0.3)
							Carex spp.	-	0.5 (0.4)
							Crepis tectorum	CR	0.5 (0.2)

LFH refers to LFH mineral soil mix, peat refers to peat mineral soil mix.
Numbers are means with standard errors in brackets, n = 3.
2006, 2007, 2008 data from Mackenzie (2012a).

Table 2.37. Dominant species at Aurora in the fifth year after reclamation.

Cover soil	Substrate	Application depth (cm)	Total cover (%)	Dominant species	C-S-R type	Cover (%)	Subdominant species	C-S-R type	Cover (%)
LFH	Sand	10	24.6 (2.2)	*F. virginiana*	C/SC or SC	5.2 (1.7)	*E. innovatus*	C/CSR	1.7 (0.8)
				E. angustifolium	C	5.1 (0.5)			
				Moss spp.	-	4.8 (0.8)			
LFH	Sand	20	61.6 (9.5)	Moss spp.	-	23.2 (6.4)	*F. virginiana*	C/SC or SC	12.3 (5.6)
							E. angustifolium	C	8.7 (1.8)
LFH	Peat-sand	10	33.6 (10.7)	Moss spp.	-	9.6 (6.7)	*E. angustifolium*	C	4.7 (0.1)
							F. virginiana	C/SC or SC	4.5 (4.0)
							R. acicularis	C or C/CR	3.4 (2.5)
							Carex spp.	-	2.3 (0.8)
							E. innovatus	C/CSR	1.9 (1.4)
LFH	Peat-sand	20	55.2 (13.0)	Moss spp.	-	15.0 (6.2)	*F. virginiana*	C/SC or SC	10.9 (10.4)
							E. angustifolium	C	8.1 (1.7)
							R. acicularis	C or C/CR	4.2 (2.4)
							E. innovatus	C/CSR	3.9 (1.6)
Peat	Peat-sand	-	10.8 (1.6)	*S. arvensis*	CR	4.8 (1.3)	*K. macrantha*	S	1.2 (0.5)
							A. ciliolatus	C	1.1 (0.3)
							Carex spp.	-	0.9 (0.3)

LFH refers to LFH mineral soil mix, peat refers to peat mineral soil mix.
Numbers are means with standard errors in brackets, n = 3.
2006, 2007, 2008 data from Mackenzie (2012a).

Table 2.38. Dominant species at W1 dump in the first year after reclamation.

Cover Soil	Application depth (cm)	Total cover (%)	Dominant species	CSR type	Cover (%)	Subdominant species	CSR type	Cover (%)
LFH	10	1.0 (0.1)	*Epilobium angustifolium*	C	0.4 (0.0)	*Sonchus arvensis*	CR	0.1 (0.1)
						Rosa acicularis	C or C/CR	0.1 (0.0)
						Fragaria virginiana	C/SC or SC	0.1 (0.0)
	20	3.1 (0.7)	*Sonchus arvensis*	CR	0.9 (0.4)	*Carex* spp.	-	0.2 (0.2)
			Epilobium angustifolium	C	0.8 (0.4)	*Rosa acicularis*	C or C/CR	0.2 (0.0)
Peat	10	0.3 (0.1)	*Epilobium angustifolium*	C	0.1 (0.0)	-		
			Sonchus arvensis	CR	0.1 (0.1)	-		
			Salix spp.	C	0.1 (0.0)	-		
	20	0.1 (0.0)	*Salix* spp.	C	0.1 (0.0)	*Equisetum arvense*	CR	0.0 (0.0)
						Calamagrostis canadensis	C/CSR	0.0 (0.0)
						Betula papyrifera	C/SC	0.0 (0.0)

LFH refers to LFH mineral soil mix, peat refers to peat mineral soil mix.
Numbers are means with standard errors in brackets, n = 3.
2004, 2005, 2006 data from Mackenzie (2006), Mackenzie (unpublished).

Table 2.39. Dominant species at W1 dump in the second year after reclamation.

Cover soil	Application depth (cm)	Total cover (%)	Dominant species	CSR type	Cover (%)	Subdominant species	CSR type	Cover (%)
LFH	10	20.5 (1.0)	*Epilobium angustifolium*	C	6.1 (0.8)	*Sonchus arvensis*	CR	2.7 (0.9)
						Fragaria virginiana	C/SC or SC	1.7 (0.1)
						Crepis tectorum	CR	1.4 (0.3)
LFH	20	36.1 (0.9)	*Epilobium angustifolium*	C	10.5 (2.6)	*Crepis tectorum*	CR	2.6 (0.3)
			Sonchus arvensis	CR	8.7 (1.5)	*Rubus idaeus*	SC	2.1 (0.5)
Peat	10	6.1 (0.3)	*Crepis tectorum*	CR	1.2 (0.1)	*Sonchus arvensis*	CR	1.1 (0.6)
						Epilobium angustifolium	C	0.9 (0.2)
						Equisetum arvense	CR	0.6 (0.1)
						Salix spp.	C	0.4 (0.2)
						Atriplex subspicata	-	0.4 (0.2)
						Carex spp.	-	0.4 (0.2)
						Potentilla norvegica	C/CR	0.3 (0.0)
						Agrostis scabra	-	0.3 (0.1)
Peat	20	5.0 (0.3)	*Crepis tectorum*	CR	0.9 (0.3)	*Epilobium angustifolium*	C	0.6 (0.4)
						Carex spp.	-	0.5 (0.0)
						Equisetum arvense	CR	0.5 (0.1)
						Geranium bicknellii	SC	0.5 (0.3)
						Agrostis scabra	-	0.4 (0.2)
						Sonchus arvensis	CR	0.3 (0.3)
						Potentilla norvegica	C/CR	0.3 (0.1)

LFH refers to LFH mineral soil mix, peat refers to peat mineral soil mix.
Numbers are means with standard errors in brackets, n = 3.
2004, 2005, 2006 data from Mackenzie (2006), Mackenzie (unpublished).

Table 2.40. Dominant species at W1 dump in the third year after reclamation.

Cover soil	Application depth (cm)	Total cover (%)	Dominant species	CSR type	Cover (%)	Subdominant species	CSR type	Cover (%)
LFH	10	45.4 (2.7)	*Epilobium angustifolium*	C	10.1 (0.3)	*Fragaria virginiana*	C/SC or SC	6.7 (1.4)
						Sonchus arvensis	CR	6.0 (1.6)
						Moss spp.	-	4.4 (1.6)
LFH	20	69.2 (2.4)	*Epilobium angustifolium*	C	15.6 (2.2)	Moss spp.	-	12.2 (2.4)
						Sonchus arvensis	CR	9.2 (2.3)
						Rubus idaeus	SC	5.9 (1.4)
						Fragaria virginiana	C/SC or SC	5.3 (1.8)
Peat	10	35.3 (1.6)	*Crepis tectorum*	CR	4.8 (0.6)	*Sonchus arvensis*	CR	3.7 (1.3)
			Epilobium angustifolium	C	4.7 (0.2)	Dicot spp.	-	3.7 (0.4)
						Equisetum arvense	CR	3.2 (0.4)
						Carex siccata	-	2.8 (0.8)
						Agrostis scabra	-	2.7 (0.6)
Peat	20	28.7 (8.5)	*Epilobium angustifolium*	C	4.2 (1.0)	Dicot spp.	-	3.6 (2.2)
						Crepis tectorum	CR	3.6 (0.9)
						Carex siccata	-	3.5 (2.2)
						Agrostis scabra	-	3.0 (0.7)
						Sonchus arvensis	CR	2.9 (0.7)

LFH refers to LFH mineral soil mix, peat refers to peat mineral soil mix.
Numbers are means with standard errors in brackets, n = 3.
2004, 2005, 2006 data from Mackenzie (2006), Mackenzie (unpublished).

Table 2.41. Dominant species at W1 dump in the seventh year after reclamation.

Cover soil	Application depth (cm)	Total cover (%)	Dominant species	CSR type	Cover (%)	Subdominant species	CSR type	Cover (%)
LFH	10	59.6 (0.4)	*Fragaria virginiana*	C/SC or SC	22.0 (4.4)	Moss spp.	-	6.8 (2.7)
						Equisetum arvense	CR	4.9 (1.0)
						Epilobium angustifolium	C	4.6 (1.1)
LFH	20	62.0 (3.6)	*Fragaria virginiana*	C/SC or SC	23.5 (0.7)	Moss spp.	-	5.8 (1.0)
						Rubus idaeus	SC	5.5 (2.5)
						Epilobium angustifolium	C	5.4 (1.2)
						Equisetum arvense	CR	4.0 (0.5)
Peat	10	50.0 (9.3)	*Equisetum arvense*	CR	10.7 (3.1)	Moss spp.	-	8.6 (1.4)
						Epilobium angustifolium	C	5.7 (0.4)
						Sonchus arvensis	CR	5.0 (1.2)
						Fragaria virginiana	C/SC or SC	4.5 (1.8)
						Taraxacum officinale	R/CSR	4.4 (0.4)
Peat	20	51.7 (2.9)	*Equisetum arvense*	CR	10.8 (1.7	*Fragaria virginiana*	C/SC or SC	7.9 (0.8)
						Epilobium angustifolium	C	5.2 (0.7)
						Salix spp.	C	4.3 (2.2)
						Moss spp.	-	4.1 (0.6)
						Taraxacum officinale	R/CSR	3.8 (0.2)
						Sonchus arvensis	CR	3.3 (0.4)

LFH refers to LFH mineral soil mix, peat refers to peat mineral soil mix.
Numbers are means with standard errors in brackets, n = 3.
2004, 2005, 2006 data from Mackenzie (2006), Mackenzie (unpublished).

Table 2.42. Dominant species at MLSB in the thirteenth year after reclamation.

Site	Cover soil	Season	Total cover (%)	Dominant species	CSR type	Cover (%)	Subdominant species	CSR type	Cover (%)
Cell 16	LFH	Winter	47.1	*Fragaria virginiana*	C/SC or SC	13.0	*Rosa acicularis*	C or C/CR	9.3
							Picea glauca	-	5.8
							Elymus innovatus	C/CSR	4.3
							Taraxacum officinale	R/CSR	4.2
							Aster ciliolatus	C	2.3
Cell 16	Peat	Unknown	28.6	*Sonchus arvensis*	CR	10.0	-	-	
				Lotus corniculatus	S/CSR	9.0	-	-	
Cell 18	LFH	Winter	77.4 (6.4)	*Fragaria virginiana*	C/SC or SC	14.4 (4.4)	*Rosa acicularis*	C or C/CR	12.2 (4.7)
				Rubus idaeus	SC	13.9 (0.8)	*Epilobium angustifolium*	C	11.3 (5.6)
							Galium borealis	C/CR or CR	3.9 (3.2)
							Aster ciliolatus	C	3.6 (0.5)
Cell 18	LFH	Summer	75.4 (4.0)	*Fragaria virginiana*	C/SC or SC	28.9 (6.0)	*Rosa acicularis*	C or C/CR	10.7 (1.3)
							Rubus idaeus	SC	7.9 (1.7)
Cell 18	Peat	Unknown	40.2 (3.0)	*Taraxacum officinale*	R/CSR	10.7 (1.1)	*Fragaria virginiana*	C/SC or SC	5.7 (0.5)
							Medicago sativa	C/CSR	5.2 (1.0)
							Lotus corniculatus	S/CSR	3.7 (1.9)

LFH refers to LFH mineral soil mix, peat refers to peat mineral soil mix.
Numbers are means with standard errors in brackets for normal data, n = 1 at Cell 16, n = 3 for LFH mineral soil mix at Cell 18, n = 2 for peat mineral soil mix at Cell 18.

CHAPTER III. AN EXAMINATION OF BARE GROUND ON LFH AND PEAT COVER SOILS IN THE ATHABASCA OIL SANDS REGION

1. INTRODUCTION

Surface mining in the Athabasca oil sands region has disturbed 715 km^2 (71,497 ha) of boreal forest in northeastern Alberta (Government of Alberta 2013). Oil sands operators have reclamation plans in place to recreate self-sustaining, locally common, boreal forests (Alberta Environment 2007a, 2007b, 2007c, 2007d, 2009, 2011). Boreal forests are naturally exposed to large scale disturbances (fires, insect outbreaks) which creates and maintains its diversity (Bonan and Shugart 1989, Chen and Popadiouk 2002). Thus boreal forests recover well after disturbance. Boreal forests can be resilient to harvesting and other human disturbances but the ecosystem is altered in different ways than by natural disturbances; resulting forest communities have different compositions and there are impacts on landscape level diversity (Hart and Chen 2006, Macdonald and Fenniak 2007).

Boreal forest recovery after oil sands mining and reclamation is a relatively new area of research relative to other forms of disturbance. After reclamation the starting point and expectations are different. Like an intense fire, the post mining environment is often missing a seed bank (unless introduced in reclamation) and the seed bed has higher temperatures due to vegetation loss, but there is no ash present. Higher temperatures can release nutrients if there is organic material in the cover soil and microbial communities to decompose it. Like post harvesting environments, soils may be compacted due to heavy machinery. Reclaimed sites generally consist exclusively of bare ground immediately prior to revegetation. A vegetation cover can develop quickly on LFH mineral soil mix and peat mineral soil mix cover soils (Mackenzie and Naeth 2010, Brown and Naeth 2014), although often not evenly across the treatment. We observed patches of bare ground and areas of sparse vegetation on both LFH mineral soil mix and peat mineral soil mix, the predominant cover soil options, at 4 to 13 year old reclamation sites. Bare mineral soil is the preferred seed bed for many plant species (Roberts 2004) and is quickly re-colonized after natural disturbances in forests. Within five to seven years after fires the seed bed is usually covered in litter and mosses (Bonan and Shugart 1989, Greene et al. 1999). As such bare patches should be a prime location for new colonizing species to invade but this has not occurred, perhaps due to erosion, lack of seeds or inhibiting soil factors.

Many soil properties can limit vegetation including shortages of nutrients (Brand 1991, Walthert et al. 2013) or water (Hogg and Wein 2005), salinity and sodicity (Maynard et al. 1997, Renault et al. 1998, Renault et al. 2000, Howat 2000), or acidity or alkalinity (Howat 2000). Soil compaction or other physical properties can impede productivity (Greacen and Sands 1980, Ampoorter et al. 2011). Property variability can be high in reclaimed soils (Leatherdale 2008), even within meters, which could explain densely vegetated areas near bare areas. On an oil sands tailings sand storage facility with peat mineral soil mix, revegetation was limited by sodicity, nutrient deficiencies and shallow cover soils depths (Burgers 2005). There have been no studies on bare areas on LFH mineral soil mix.

Understanding bare ground patterns and how they affect vegetation development on oil sands cover soils is key to improving reclamation practices for cover soil use. Cover soils for reclamation, particularly LFH mineral soil mix, are not an unlimited resource and must be used efficiently across the landscape. While these bare areas might not be cause for concern in natural regeneration following fire, they are potentially a problem in reclamation. There is an obligation for land managers to ensure that conditions are optimal for revegetation success and to correct identified problem areas, especially if it is clear that the problems came about through practices that can be improved. Bare areas may not need to be repaired but research is needed into the reasons they occur and the degree of risk they represent. They may be more problematic in the reclaimed environment than in natural settings as conditions are potentially harsher and more exposed.

2. RESEARCH OBJECTIVES

The general research objective was to determine why areas of bare ground remain 4 to 13 years after reclamation with LFH mineral soil mix and peat mineral soil mix cover soils in the Athabasca oil sands. Specific objectives follow.

- Compare vegetation characteristics and soil properties of heavily vegetated and bare areas on LFH mineral soil mix and peat mineral soil mix.

- Determine if different soil – vegetation relationships exist on bare and heavily vegetated areas and if this is affected by cover soil type.
- Compare initial soil properties at reclamation to current soil properties of bare and vegetated areas on LFH mineral soil mix and peat mineral soil mix.

3. MATERIALS AND METHODS

3.1 Study Area

Research sites were located on Syncrude Canada Ltd. (Syncrude) and Suncor Energy Inc. (Suncor) mine leases 25 to 75 km north of Fort McMurray, Alberta, in the central mixedwood natural subregion of the boreal forest natural region (Natural Regions Committee 2006). Short, warm summers and long, cold, winters are typical. Mean annual temperature is 0.7 °C; average daily maximum 23.2 °C in July and average daily minimum -24 °C in January (Environment Canada 2013). Mean annual precipitation is 455.5 mm; 342.2 mm as rain and 155.8 cm as snow. Average frost free days are 97 (Natural Regions Committee 2006). Mean wind speed is 9.5 km / h; most frequently from the east except from the southwest in July and August (Environment Canada 2013).

Topography is variable and composed of uplands and lowlands with distinct soil types. Upland soils are mainly Gray Luvisols with fine textured glaciofluvial or medium to fine textured till parent materials, with Eutric and Dystric Brunisols on drier sandy sites (Yarmuch 2003) and organic and peaty Gleysols on low areas.

Mixedwood forests with varying proportions of *Populus tremuloides* Michx. (trembling aspen), *Populus balsamifera* L. (balsam poplar) and *Picea glauca* Moench (Voss) (white spruce) are main upland vegetation types (Natural Regions Committee 2006) with *Abies balsamea* (L.) Mill (balsam fir) and *Betula papyrifera* Marsh. (paper birch). *Pinus banksiana* Lamb. (jack pine) forests occur in drier areas. Wetland vegetation consists of *Picea mariana* (Mill.) BSP. (black spruce), *Larix laricina* (Du Roi) K. Koch (tamarack) and *Salix* spp. L. (willow).

Upland plant communities are classified into five ecosites based on hydrologic and nutrient regimes (Beckingham and Archibald 1996). Lichen (a) ecosites have xeric to subxeric hydrologic and poor to very poor nutrient regimes. *Pinus* *banksiana* dominates with *Arctostaphylos uva-ursi* (L.) Spreng. (common bearberry), *Vaccinium vitis-idaea* L. (bog cranberry), *Vaccinium myrtilloides* Michx. (blueberry) and lichen in the understory. Low bush cranberry (d) ecosites have mesic hydrologic and medium nutrient regimes. *Populus tremuloides*, *Picea glauca*, *Rosa acicularis* Lindl. (prickly rose), *Viburnum edule* (Michx.) Raf. (low bush cranberry), *Shepherdia canadensis* (L.) Nutt. (Canada buffaloberry), *Rubus pubescens* Raf. (dewberry), *Aralia nudicaulis* L. (wild sarsaparilla), *Cornus canadensis* L. (bunchberry) and *Elymus innovatus* Beal (hairy wild rye) are typical species. Blueberry (b) ecosites, with submesic hydrologic and medium nutrient regimes, have elements of lichen (a) and low bush cranberry (d) ecosites. Labrador tea – mesic (c) ecosites have mesic hydrologic and poor nutrient regimes; *Pinus banksiana*, *Picea mariana*, *Ledum groenlandicum* Oeder. (Labrador tea), *Vaccinium vitis idaea*, *Vaccinium myrtilloides*, mosses and *Cladina mitis* (Sandst.) Hale & W. Culb. (reindeer lichen) are typical species. Dogwood (e) ecosites have subhygric hydrologic and rich nutrient regimes, and like low bush cranberry (d) ecosites have *Populus tremuloides* and *Picea glauca* overstories, with *Populus balsamifera* prominent. Understory species are similar to low bush cranberry (d) ecosites with *Lonicera involucrata* (Richards) Banks (bracted honeysuckle), *Cornus stolonifera* Michx. (red osier dogwood), *Mertensia paniculata* (Ait.) G. Don. var *paniculata* (tall lungwort), *Calamagrostis canadensis* (Michx.) Beauv. (marsh reed grass), ferns and horsetails.

3.2 Experimental Design

LFH mineral soil mix and peat mineral soil mix treatments at previous research sites were used (Table 3.1). Sites differed in age, substrates cover soils were placed on, salvage and application depths and source of LFH mineral soil mix. A paired design was used to compare areas of high vegetation cover and diversity to bare areas. In each treatment replicate (formerly an experimental unit) a series of paired quadrats was established, each pair had bare and vegetated quadrats generally less than 4 m apart. Sampling points based on vegetation composition allowed for targeted examination of soil properties associated with vegetation rather than characterization on each cover soil. Combined vegetation and soil sampling allowed for correlations between plant community and soil properties.

3.3 Research Site Descriptions

3.3.1 South east dump woody debris site

South east dump (SE dump) is a saline sodic overburden pile at Suncor, 25 km north of Fort McMurray (Brown 2010, Brown and Naeth 2014). The 70 by 300 m study area is mid slope, facing east southeast. A complete randomized design has 6 *Picea mariana* and *Populus tremuloides* woody debris treatments on LFH mineral soil mix and peat mineral soil mix and controls without woody debris. Treatments are replicated 6 times, with 36 experimental units (10 by 30 m) and 5 m buffers, in two rows separated by a 10 m buffer (Figure 3.1). Slopes in the bottom row (6 to 10 %) are steeper than in the top (2.5 to 6 %).

Soil covers were applied in November 2007, separated from saline sodic overburden by 100 cm of clean overburden. LFH mineral soil mix was salvaged to 20 cm, stockpiled 3 months, and 20 cm applied over 30 cm of mixed B and C horizons. LFH mineral soil mix was salvaged from mesic b and d ecosites with *Populus tremuloides*, *Picea glauca* and *Pinus banksiana* (Meaney 2012). Peat mineral soil mix (30 cm) was applied on overburden; no peat mineral soil mix salvage information was obtained. Materials were spread with a D6 Caterpillar bulldozer. Plots were fertilized in June 2008 with 23.5:25:8 (nitrogen: phosphorus:potassium) at 300 kg / ha with a fixed wing aircraft. Fertilizing (31.5:16:5) continued annually from 2009 to 2011 at 250 kg / ha.

3.3.2 W1 overburden storage facility

W1 overburden storage facility (W1 dump) is at Syncrude base mine 40 km north of Fort McMurray (Mackenzie 2006, Mackenzie and Naeth 2010). It is a saline sodic overburden dump covered with 90 cm of secondary material (fine textured, non-saline, non-sodic overburden) in February 2004. Saline sodic overburden is marine shale of the Clearwater Formation with electrical conductivities >4 dS / m and sodium adsorption ratios of 18 to 37 (Fung and Macyk 2000).

The site is on a mid to upper slope with southeast aspect, the warmest and driest position in the landscape. Three 12 to 46 m long slopes (6 to 16 %) and two 12 to 46 m long benches (0 to 6 %) are on a 300 by 150 m study area in a complete randomized design with four treatments, each replicated three times (12 experimental units) (Figure 3.2). Treatments are 10 and 20 cm LFH mineral soil mix and peat mineral soil mix in 25 by 150 m strips. There are no buffers due equipment size constraints. Peat mineral soil mix was applied to the rest of the overburden pile.

LFH mineral soil mix, of LFH layers (mean depth 7.5 cm), eluvial A, transitional AB and illuvial B horizons, was salvaged to 20 cm and stockpiled in November 2003. Peat mineral soil mix was obtained by stripping a peat layer > 40 cm deep and mineral soil below in November 2003. Cover soils were applied February 28 and 29, 2004. Average depths for 10 and 20 cm treatments were 12.8 and 21.3 cm, respectively. D10 Caterpillar bulldozers were used to strip and spread. Large frozen lumps were flattened with pipes in June 2005 on peat mineral soil mix. In fall 2005 *Populus tremuloides* and *Picea glauca* seedlings were planted (Vassov 2012, Mackenzie 2012a).

The LFH mineral soil mix donor site was vegetated with *Populus tremuloides,* and a few *Picea glauca* and associated understory species including *Salix* spp. (willows), *Rosa acicularis*, *Calamagrostis canadensis*, *Carex* sp. L. (sedges), *Fragaria virginiana* Duchesne ssp. *glauca* (S.Wats.) Staudt. (wild strawberry), *Epilobium angustifolium* L. ssp. *angustifolium* L (fireweed), *Aster ciliolatus* Lindl. (Lindey's aster) and *Petasites palmatus* (Ait.) A. Gray (palmate-leaved colts foot). Peat mineral soil mix was salvaged from a site dominated by *Salix* sp., *Ledum groenlandicum*, *Oxycoccus microcarpus* Turcz. (small bog cranberry), *Vaccinium vitis-idaea*, *Carex* sp. and *Calamagrostis canadensis.*

3.3.3 Mildred Lake Settling Basin

Mildred Lake Settling Basin (MLSB), a tailings dyke surrounding a tailings pond, is at Syncrude base mine. Three treatments were at Cell 18 toe berm, two at Cell 16 to 19 beach (Cell 16) (Lanoue and Qualizza 2000) (Figure 3.3). Treatment and control areas were 50 by 50 m. LFH material was salvaged in August 1998 at an average 7.8 cm depth from a dry upland *Populus tremuloides* dominated pre-mining area (deforested 1996) and windrowed a few days later. Undisturbed soil was an Orthic Gray Luvisol with shallow (0 to 5 cm) LFH and sandy Ae horizons. Although less mineral material was expected to be mixed with LFH at this salvage depth, the term LFH mineral soil mix was used.

LFH mineral soil mix was placed on Cell 18 in late August 1998 over peat mineral soil mix placed in 1997 (Pollard 2001). In mid January 1999, remaining LFH mineral soil mix was placed at Cells 18 and 16, using Caterpillar 777 and 789 trucks and bulldozers. Cell 18 treatments are summer and winter placement of 11 to 13 cm of LFH mineral soil mix (3 replicates each) over 18 cm peat mineral soil mix over 35 cm secondary material and a control with the same 18 cm peat mineral soil mix over 35 cm secondary (2 replicates) (Figure 3.3). Summer placements are east of winter placements. Slopes are 11 to 14 %, facing N to N NE. Cell 16 treatments are winter placed 18 cm of LFH mineral soil mix and peat mineral soil mix over 23 cm secondary, with no replicates (Figure 3.3). Cell 16 slopes are 1 % or less. Summer and winter placement is confounded by stockpiling which significantly affects seed bank viability (Mackenzie 2012b). Winter treatments were with stockpiled material, summer treatments with direct placed. Thus direct placement and short term stockpiling are compared.

Peat mineral soil mix treatments were fertilized at 500 kg / ha with 10:30:15:4 (nitrogen:phosphorus:potassium:sulfur) and seeded to barley in 1998 at Cell 18 and 1999 at Cell 16 (McMillan et al. 2007). Trees were planted at Cell 16 in September 2000 (1:1 *Populus tremuloides – Picea glauca* mix at 2,019 stems / ha) and at Cell 18 in August 2005 (1:1.1 *Populus tremuloides* and *Pinus banksiana* at 1,981 stems / ha) (Yarmuch 2013).

3.4 Vegetation And Soil Sampling At Paired Quadrats

3.4.1 Paired quadrats

Paired quadrat locations were selected by first locating patches with > 80 % bare ground, then locating a vegetated patch within a few metres. Vegetated patches had high canopy cover and species diversity with mixed graminoids, herbaceous plants and shrubs. GPS coordinates and slope position of each pair were recorded; slope percent was determined by associating slope position with previously measured slope data (Tables B.1, B.2, B.3, B.4, B.5, B.6). Distances between bare and vegetated quadrats were measured.

Small hummocks (50 cm high or less) were observed on several of the LFH mineral soil mix and peat mineral soil mix cover soil treatment replicates at W1 dump which likely act as microsites and influence the vegetation community. The hummocks were an unintended side effect of spreading material in the winter (Mackenzie 2006, Mackenzie and Naeth 2010). Large frozen lumps of peat were observed after spreading and remedial flattening was carried out in spring on the peat mineral soil treatments, but not on LFH mineral soil mix. Observing these types of effects was not the goal of this project and paired quadrats were placed away from these hummocks so there were no microtopographical differences between paired bare and vegetation patches. There were no differences in microtopography between patch types at SE dump or MLSB.

Sample numbers varied with site and treatment based on presence and location of bare ground. Within each cover soil treatment replicate (experimental units in Chapter 2) vegetation assessments, penetrometer readings and soil sampling were conducted at 5 to 7 pairs at W1 dump, 2 to 5 pairs at SE dump, 1 to 4 pairs at Cell 16 and 2 to 3 pairs at Cell 18 (Tables B.1, B.2, B.3, B.4, B.5, B.6). Not all quadrats assessed for vegetation were soil sampled due to time constraints although all quadrats were included in bare and vegetated patch comparisons.

3.4.2 Vegetation assessment

Vegetation was assessed in 0.1 m^2 (20 x 50 cm) quadrats at W1 dump, SE dump and MLSB August 4 to 11, 2011. General vegetation composition of the 1 m^2 area around each quadrat was sketched and identified. Photos were taken of the quadrat and of the 1 m^2 area around it.

Ocular assessments were conducted for canopy cover by species; ground cover of live vegetation, litter, bare ground, woody debris, rocks (≤ 2 cm diameter were considered bare ground) and moss; and density of woody species. MLSB vegetation was heavily grazed by grasshoppers, affecting canopy cover estimates for some species; cover was assessed as though plants were not eaten. Only plants rooted in the quadrat were included, except *Arctostaphylos uva-ursi* (L.) Spreng (bearberry) because it is low growing with extensive trailing branches. Each quadrat was given a biomass rating from 1 to 3 based by visualizing how much of a paper bag would be filled by clipped vegetation.

Canopy cover by species was used to calculate species richness, native species richness, non-native species richness and percent cover of grasses, sedges, forbs, pteridophytes, mosses, shrubs, trees, native species and non-native species per quadrat. Total cover was tabulated from individual species cover; hence, some quadrats had covers ≥ 100 %. Vegetation trace values were set to 0.01 % in mathematical calculations and statistics. Unknown species and plants identified to genus were included if it was clear which group they belonged to. Information on growth form and origin was from Moss (1994), Tannas (2003a, 2003b, 2003c) and Johnson et al. (1995).

Total cover and cover of growth forms and origin groups were not compared between bare and vegetated quadrats. Proportions of total cover these growth forms and origin groups occupied on bare and vegetated quadrats were compared to determine if types of species were preferentially found at bare or vegetated patches. Proportions were calculated at quadrat level by dividing cover of the group by total cover and multiplying by 100. Values were averaged for each cover soil. Woody plant density was total number of shrubs and trees per quadrat. The 0.1 m^2 quadrats were converted to m^2 by multiplying by 10.

Some species identification issues that occurred during quadrat assessments were corrected during analysis. Although some specimens of *Agropyron trachycaulum* (Link) Malte (slender wheat grass), *Agropyron repens* (L.) Beauv. (quackgrass), and *Agropyron hirtiflorus* (A.S. Hitchc.) Bowden were difficult to distinguish at Cell 16 and 18, they were left as separate entries as they all occurred on site. *Medicago* specimens at Cells 16 and 18 were called *Medicago sativa* L. (alfalfa) although some *Medicago falcata* L. (yellow lucerne) was present; the latter observed in surrounding areas after vegetation assessments. *Fragaria vesca* L. (woodland strawberry) may have occurred on some sites but was lumped with *Fragaria virginiana* as identification differed among assessors. *Carex* specimens were only identified to species when flowering parts were available; *Carex* specimens in vegetative form could not be identified to species.

3.4.3 Soil sampling

Soil was sampled August 10 and 17 to 24, 2011 after vegetation assessment. Sampling began with placement of quadrats in the same location as vegetation assessments. Vegetated quadrats were cleared of vegetation by hand pulling prior to soil sampling; litter was left intact and collected.

At each quadrat a small hole was dug with a trowel and cover soil depth was measured with a tape measure. Cover soil generally differed from substrate material in colour and structure. LFH mineral soil mix was gray and fluffy with bits of leaf litter and generally had small soil peds. Peat mineral soil mix was darker, with peaty material visible. Substrate material, in this case usually secondary or a mix of B and C horizon material, was brown with large peds. The term substrate was used to describe both secondary material and the mix of B and C horizon material even though the latter could be described as subsoil; subsoil has undergone soil forming processes while substrate is a more general term that includes soil and soil-like material. Replicate 3 of 10 cm LFH mineral soil mix at W1 dump was problematic; the LFH mineral soil mix layer was not distinct hence likely sampled with secondary material. Cover soil was collected separately from substrate material and its depth recorded. Substrate to a maximum depth of 30 cm from the surface was collected. If cover soil extended to 30 cm, it was collected at 0 to 15 and 15 to 30 cm. If cover soil was not obvious and the upper 30 cm of soil looked the same, 0 to 15 and 15 to 30 cm samples were collected.

Layer based sampling, rather than depth sampling which combines different materials, was used to reduce variability (Belanger and Van Rees 2008) with one exception. Layers < 5 cm in depth were combined as not enough could be collected inside the quadrat. For example, at W1 dump there was often a whitish surface layer that may have been eroded material from up slope, but it was generally < 5 cm deep. In some cases layers of different material were found at the pit bottom; if it was < 5 cm in depth it was either combined with the lower layer or not sampled and total sampling depth at that quadrat was recorded as depth at which new material was found. Collecting an additional sample each time there was a small third layer would have greatly exceeded the budget and increased sampling time. Mineral type soil layers at the surface on top of the organic cover soil layer made defining cover soil depth difficult. Statistics were run on two different scenarios: one where depth was recorded as the thickness of organic material and another where the entire layer above the substrate material was recorded (mineral material and organic material combined).

Cover soil and substrate samples were collected from the same hole used to determine depth of cover soil (generally half a quadrat) and from one to several auger holes on the other side of the quadrat to gather soil from the entire quadrat. Bare quadrat sampling only occurred in the bare patch. Augering was done carefully so as not to mix materials. Excess soil was placed on tarps during sampling to facilitate replacement into the hole and to minimize disturbance to vegetation around sampling points. Samples for each layer at each quadrat were collected in buckets and mixed by hand; large clods were broken to ensure a representative sample of the entire quadrat. Soil was transferred to plastic bags, placed in coolers with ice packs and transported to a commercial laboratory.

3.4.4 Soil analyses and measurements

Soil pH, electrical conductivity (EC), exchangeable cations (calcium, magnesium, sodium, potassium), cation exchange capacity (CEC), total exchange capacity (TEC), exchangeable sodium percentage (ESP), base saturation, total inorganic carbon (TIC), total organic carbon (TOC), organic matter (OM) and total nitrogen (TN) were analyzed at a commercial laboratory (Table 3.2). Total carbon was the sum of inorganic and organic carbon. Carbon to nitrogen ratio (C:N) was total carbon divided by total nitrogen. Pairs with total nitrogen below detection limit were removed from statistical analysis.

Sand, silt and clay content (texture) were determined at a commercial laboratory (Table 3.2). Soil wettability was measured on 8 samples from the upper few cm of soil at bare patches to assess surface hydrophobicity. No hydrophobicity was found and further testing was not conducted (Table 3.3).

Gravimetric water content was determined in upper layers at -0.1, -0.3 and -15 bar (-10, -30, -1500 kPa) by pressure extraction (Reynolds and Topps 2008) for field capacity, wilting point and water holding capacity calculations. Field capacity is water content at -10 to -30 kPa (Brady and Weil 2004). As samples were not intact soil core water holding capacity was calculated with -30 kPa instead of -10 kPa data (Reynolds and Topp 2008). Samples were air dried and sieved to 2 mm prior to pressure extraction. Reference samples were used to check for consistency among runs; some were > 1 standard deviation from the mean for that pressure. When samples could be tied to a specific reference value, sample data were multiplied by the product of the average reference value for that pressure divided by the reference value for that run, or vice versa depending if the reference value was higher or lower than average. Approximately 25 of 625 samples were corrected. Some samples could not be corrected and were re-run.

Bulk density samples were collected at the soil surface from the edge of vegetated and bare quadrats with a Uhland core (7.5 cm diameter, 13 cm length) (Mckeague 1978). Wet and oven dry (105 °C) weights were used to calculate volumetric water content and bulk density. Rocks > 15 g were removed; their weight and volume were determined and subtracted.

Three penetrometer readings per quadrat were taken at 5, 10, 15, 20, 25 and 30 cm with a Soiltest Model CN973 penetrometer. The cone was 1.2 cm in diameter and 2.1 cm in length. In some cases soil was too firm and readings could not be obtained for all depths. Values were recorded in pounds per square inch (PSI) and converted to MPa using a formula to account for cone size. Penetrometer readings were taken on August 8, 10, 11, 17 to 22, 2011. There was some rain during this time but likely not enough to affect readings. The penetrometer stopped working before readings could be taken at SE dump. For each quadrat an average of three readings was calculated for each depth and used in correlation analysis. The maximum value for each of the three runs and the depth at which it occurred were noted and average values calculated for each quadrat; these were used in statistical comparisons between bare and vegetated patches.

3.5 Statistical Analyses

A mixed model analysis of variance (ANOVA) was used to compare soils in bare and vegetated areas. Using SAS statistical software (version 9.3, SAS Statistical Institute) each site and cover soil was analyzed. Since bare and vegetated states were of interest, cover soil replicates were treated as blocks and paired quadrats were experimental units; pairs were nested within blocks. State (bare, vegetated) was a fixed factor in mixed model analysis; block, pair and state-block interaction were random factors. For W1 dump data application depth was a fixed factor; block was nested in application depth and pair nested in block and application depth. Cells 16 and 18 data were combined and treated as blocks.

For many soil properties, outliers resulted in failure of normality and homogeneity of variance tests. Outliers were not outside the range of variability previously reported in the oil sands region for these materials (Paragon and Jacques Whitford Axys 2009), indicating they did not likely result from laboratory errors and should be included in analyses. A proc mixed procedure for unequal variances using the repeated statement in SAS statistical software (version 9.3, SAS Statistical Institute) was used to account for differences in variances. The recourse for non-normal data was transformation; log transformation was useful in some but not all data sets. As there is no non-parametric analogue to nested mixed model analysis, the analysis was performed on data sets that failed assumptions of normality; the same analysis was performed with outliers removed (sensitivity analysis). P values were similar and the same conclusion drawn. There were several problematic data sets for which SAS proc mixed procedure for unequal variances was unable to model and calculate a solution and error messages such as “did not converge” and “stopped due to infinite likelihood” appeared, even after transformation or removal of outliers. Thus differences between bare and vegetated are discussed qualitatively.

Separate ANOVAs were run on upper and lower layer samples for each soil chemical and physical property. These terms were used instead of cover soil and substrate samples because although upper layer samples were often composed of cover soil material, when there was no distinct cover soil the upper layer sample was 0 to 15 cm of substrate material. Similarly, lower layer samples were often substrate material but in some cases cover soil was 30 cm deep and divided into 0 to 15 and 15 to 30 cm depth intervals. As a result of layer-based sampling some comparisons between bare and vegetated quadrats were between layers of different depths. For example, a vegetated quadrat may have had a cover soil depth of 22 cm while the paired bare patch may have had no discernible cover soil and a substrate sample was collected to 15 cm. When lower layer samples were compared in this case the comparison was between 8 cm and 15 cm layers. Regardless, compared data were specific to those layers.

A separate analysis of upper layer properties at W1 dump was used to compare 2011 and first growing season data (collected by Mackenzie 2006, Mackenzie and Naeth 2010). T-tests were used to compare initial conditions to bare and vegetated quadrats. Non-parametric Wilcoxon-Mann-Whitney t-tests were used when data failed normality tests. T-tests were considered significant at $p < 0.05$

for parametric tests and $p < 0.1$ for non-parametric tests. No analysis was possible for lower layer W1 dump data or for SE dump or MLSB data.

Correlations were run to determine relationships; vegetation and soil, vegetation and ground cover and vegetation and slope. Quadrats were experimental units although there was no way to account for nesting in cover soil treatment replicates. Separate correlation analyses were run for bare and vegetated quadrats on cover soils at each site. Spearman rank order correlation was used as many data sets failed normality tests. Correlations were significant at $p < 0.05$.

Some bare patches had < the 80 % bare ground originally intended, generally due to patches smaller than quadrats. This did not affect comparison of soil property comparison as soil was collected from the bare patch. It potentially affected correlation analyses as some vegetation was not in the bare area. Quadrats with low bare ground are intermediates between bare and vegetated states and may obscure large, bare area trends. W1 dump analysis was run with and without questionable quadrats with similar results (many same correlations were significant), although upon examination of scatter graphs, questionable quadrats were almost outliers. Only results with questionable patches removed are reported. At W1 dump sample size was large enough (30 bare, 30 vegetated quadrats) for small bare patches to be removed from correlation analysis; at SE dump and MLSB sites there were only 4 to 10 bare patches.

4. RESULTS

4.1 Ground Cover Characteristics Of Bare Patches

Bare patches on LFH mineral soil mix varied with site (Tables 3.4, 3.5, 3.6). W1 dump bare patches were > 80 % bare ground with three exceptions (48 to 64 %). At SE dump only one quadrat had > 80 % bare ground; most had 70 - 80 % and two had < 35 %. Cell 18 bare patches were small with < 12 % bare ground. Most Cell 16 bare patches had > 80 % bare ground; one had 10 %. Many low bare ground patches had high litter cover.

Peat mineral soil mix bare patches varied in size (Tables 3.7, 3.8, 3.9). W1 dump bare patches had > 80 % bare ground except 4 quadrats with 8 to 70 %. SE dump bare ground averaged 73 % (40 to 94 %) with only 5 of 10 quadrats > 80 %. At Cell 18, half the quadrats had > 80 % bare ground; one had 75 % and two had < 10 %. Cell 16 bare patches were > 80 % bare ground.

4.2 Vegetation In Bare And Vegetated Patches

4.2.1 LFH mineral soil mix

Quadrat species richness, quadrat native species richness and quadrat non-native species richness at bare patches were inconsistent across sites (Tables 3.4, 3.5, 3.6). Bare patch averages at Cell 18 were similar to W1 dump, with lower maximums. Average richness and native richness at Cell 16 were lower than at W1 dump and Cell 18; non-native richness was higher. Maximums were lower at Cell 16 than W1 dump. SE dump averages and maximums were highest; bare and vegetated patches were similar (Table 3.5). Vegetated patches at W1 dump and Cells 16 and 18 had higher quadrat richness, quadrat native richness and quadrat non-native richness than bare patches (Tables 3.4, 3.6). Maximums were higher at vegetated patches; non-native richness was the same.

At site level (all quadrats), W1 dump and Cells 16 and 18 bare patches had fewer species than vegetated patches; at SE dump bare and vegetated patches species richness was similar (Tables 3.10, 3.11, 3.12). *Poa pratensis* L. was unique to W1 dump bare patches and SE dump vegetated patches. SE dump bare patches had 5 unique species (*Bromus ciliatus* L. (fringed brome), *Epilobium ciliatum* Raf. (fringed willow herb), *Lathyrus venosus* Muhl. (veiny pea), *Potentilla norvegica* L. (rough cinquefoil), aster); 3 on vegetated patches at W1 dump. *Agropyron hirtiflorus* and *Equisetum arvense* L. (common horsetail) were specific to bare patches at Cell 18, and were found on both patches at other sites. *Agropyron repens* was unique to bare patches at Cell 16 but was found on both patches at other sites. No species were unique to bare patches across sites.

Regardless of number of species at bare patches, all sites had 2 to 4 non-natives (Tables 3.10, 3.11, 3.12). Proportions of native and non-native species were similar on bare and vegetated patches at W1 dump and Cell 18; SE dump and Cell 16 bare patches had a higher proportion of non-native species cover than vegetated patches (Tables 3.13, 3.14, 3.15, 3.16).

Growth forms on bare patches varied across sites (Tables 3.13, 3.14, 3.15, 3.16). Bare patches had no trees and were dominated by forbs. Forbs comprised > 80 % of cover at W1 dump and Cells 18 and 16 and 50 % at SE dump with grass and shrubs > 15 % of cover. Bare and vegetated patches had different growth forms at all sites. W1 dump bare and vegetated patches had similar proportions of grass, sedge, pteridophyte and moss cover; vegetated patches had a lower proportion of forb and higher proportion of shrub cover. SE dump bare and vegetated patches had similar forb and grass proportions; vegetated patches had a greater proportion of shrub cover and bare patches had greater moss. Cell 18 bare patches were dominated by forbs; vegetated patches were co-dominated by forbs and shrubs. Cell 16 vegetated patches were dominated by forbs, with shrubs occupying a notable proportion. Vegetated patches had a higher proportion of shrub cover than bare patches at all sites.

4.2.2 Peat mineral soil mix

SE dump bare patches had highest average and maximum quadrat richness and quadrat native species richness; average and maximum quadrat non-native species richness was similar across sites (Tables 3.7, 3.8, 3.9). Cell 18 average and maximum species richness, native richness and non-native richness on bare patches were low. Cells 16 and 18 native species richness was the same; species richness and non-native richness were higher at Cell 16. Cell 16 bare patches had more non-native than native species. W1 dump and Cells 16 and 18 vegetated patches had greater average and maximum species richness, native richness and non-native richness than bare patches. SE dump vegetated patches had greater species richness and native richness than bare patches; non-native richness was similar. Maximum species richness and native richness were similar on both patches, with higher maximum non-native richness on bare.

At the site level (all quadrats combined) vegetated patches had more species than bare patches at W1 dump and Cells 18 and 16; at SE dump number of species was similar (Tables 3.17, 3.18, 3.19). At SE dump 6 species were unique to bare patches including *Agropyron repens*, *Calamagrostis canadensis*, *Chenopodium album*, *Erigeron canadensis* L. (horseweed), *Urtica dioica* L. (common nettle) and an unidentified grass. *Agropyron repens* and *Calamagrostis canadensis* were on bare and vegetated patches at some of the other sites;

Chenopodium album, *Erigeron canadensis* and *Urtica dioica* were not at other sites. No species were unique to bare patches at the other sites.

Growth forms on bare patches on peat mineral soil mix varied by site (Tables 3.20, 3.21, 3.22, 3.23). Forbs dominated; pteridophytes subdominated on bare patches at W1 dump; moss subdominated at SE dump and Cells 16 and 18. Bare and vegetated patches differed at all sites; shrubs replaced pteridophytes and mosses as subdominants on vegetated patches at W1 dump and SE dump, respectively. Cell 18 vegetated patches were dominated by forbs; Cell 16 dominant and subdominants were the same as bare patches. Bare patches on peat mineral mix had a higher proportion of non-native cover than vegetated patches at all sites (Tables 3.20, 3.21, 3.22, 3.23).The most dramatic difference occurred at SE dump where only 5 of 23 species were non-native but comprised half the total cover (Tables 3.18, 3.21).

4.3 Soil Properties Of Bare And Vegetated Patches

4.3.1 Depth of cover soil

Cover soil depth at vegetated patches on both cover soils at W1 dump was significantly greater than at bare patches (Tables 3.24, 3.25, 3.26, 3.27). Prescribed cover soil application depth did not significantly affect measured cover soil depth. At SE dump cover soil depth of bare and vegetated patches did not differ significantly on LFH mineral soil mix and peat mineral soil mix (Tables 3.28, 3.29). Vegetated patches on peat mineral soil mix had numerically greater cover soil depth than bare patches; ranges overlapped substantially. MLSB cover soil depth was similar on bare and vegetated patches on either cover soil (Tables 3.30, 3.31, 3.32, 3.33).

4.3.2 Carbon and nitrogen

Vegetated patches had significantly higher upper and lower layer OM, TOC and TC and upper layer TN than bare patches on LFH mineral soil mix at W1 dump, with no differences due to application depth (Tables 3.34, 3.35). Bare patches had significantly higher upper layer C:N than vegetated patches (Table 3.34). Cover soil depth did not significantly affect C:N; an application depth and treatment interaction effect was significant for upper layer TIC. Bare patches on

10 cm LFH mineral soil mix had significantly higher upper layer TIC than vegetated patches, with no significant differences on 20 cm LFH mineral soil mix.

Upper layer OM, TOC, TIC, TC and TN did not differ significantly on bare and vegetated patches on LFH mineral soil mix at SE dump or MLSB; nor did C:N at SE dump (Tables 3.36, 3.37). SE dump vegetated patches had higher values than bare patches, except C:N was similar. Non heterogeneity at MLSB prevented C:N statistical analysis (Table 3.37); trends varied by block. Vegetated patches had higher OM, TOC, TC and TN and lower TIC and C:N than bare patches at Cell 16; Cell 18 had similar values at bare and vegetated patches.

Statistical analysis of SE dump lower layer OM, TOC, TIC, TC or TN on LFH mineral soil mix was not possible due to variance inequality (Table 3.38). Bare patches had higher OM, TOC, TIC, TC and TN than vegetated and similar medians. C:N did not differ significantly between bare and vegetated patches. MLSB lower layer OM, TOC, TIC, TC or C:N did not differ significantly between bare and vegetated (Table 3.39). TN could not be analyzed due to unequal variances; differences were likely insignificant with similar values at 3 of 4 blocks.

Vegetated patches on peat mineral soil mix at W1 dump had significantly higher upper layer OM, TOC, TC and TN than bare patches (Tables 3.40). There were significant differences regardless of outlier inclusion. Upper layer C:N was only statistically higher on bare patches when an outlier (133:1) was removed. There were no significant differences in lower layer OM, TOC, TC, TN and C:N, although removing outliers changed the first three parameters (Table 3.48). There were no significant differences in upper and lower layer TIC regardless of outliers (Tables 3.40, 3.41). Cover soil depth did not affect any parameters.

Bare and vegetated patches did not differ significantly for upper layer OM, TOC, TIC, TC or TN on peat mineral mix at SE dump and MLSB, or in upper layer C:N at SE dump (Tables 3.42, 3.43). Upper layer C:N at MLSB could not be analyzed due to unequal variances (Table 3.43). SE dump bare and vegetated patches had similar upper layer OM, TOC, TIC, TC, TN and C:N; upper layer values at MLSB bare and vegetated patches were different at each block. Vegetated patches at one Cell 18 block had higher upper layer OM, TOC, TIC, TC and TN, and bare patches had higher C:N; differences were minor at other blocks. Small sample size (2 at Cell 16, 3 at Cell 18) reduced confidence in the trends. No significant differences in lower layer OM, TOC, TIC, TC, TN and C:N were found for SE dump (Table 3.44). Average lower layer values at vegetated patches were almost double those at bare (except TIC and C:N) but overlapping ranges and large variability likely resulted in lack of significant differences. There were no significant differences in lower layer TIC or C:N between bare and vegetated patches at MLSB (Table 3.45). Statistical modelling issues prevented analysis for lower layer OM, TOC, TC, and TN. Average and median values for these lower layers were similar for bare and vegetated patches at all blocks.

4.3.3 Exchangeable cations

W1 dump vegetated patches on LFH mineral soil mix had significantly higher upper layer exchangeable magnesium and potassium and CEC than bare patches; base saturation was significantly higher at bare patches (Table 3.34). Cover soil depth had no significant effect on these parameters. Due to lack of homogeneity and normality differences between vegetated and bare patches in exchangeable sodium and ESP were not analyzed. Significant differences in sodium are unlikely as neither patch type had consistently higher values (Tables 3.34, 3.35). Numerically upper layer ESP was higher at bare patches,

At SE dump there were no significant differences in upper layer exchangeable calcium, base saturation, ESP, TEC or CEC or in upper or lower layer exchangeable magnesium, sodium and potassium on LFH mineral soil mix (Tables 3.36, 3.38). Lower layer exchangeable calcium, base saturation, ESP, TEC or CEC could not be analyzed statistically due to lack of heterogeneity (Table 3.38). Average values for these parameters differed numerically but median values for bare and vegetated patches were similar.

The only significant difference in soil properties between bare and vegetated patches at MLSB was upper layer exchangeable potassium on LFH mineral soil mix, being highest on vegetated patches (Table 3.37). Upper layer base saturation could not be analyzed due to unequal variances; no significant differences in lower layer occurred (Tables 3.37, 3.39). Upper layer base saturation did not differ with patch type at Cell 18, but did at Cell 16.

W1 dump vegetated patches on peat mineral soil mix had significantly higher upper layer exchangeable calcium, magnesium and potassium, TEC and CEC than bare patches (Table 3.40), which had significantly higher upper and lower layer base saturation (Tables 3.40, 3.41). Upper layer exchangeable sodium was numerically higher on vegetated than bare patches (Table 3.40). There were no significant cover soil application depth effects or related trends for these parameters. There were no significant differences in upper or lower layer exchangeable cations or base saturation, CEC, TEC or ESP between bare and vegetated patches on peat mineral soil mix at SE dump and MLSB (Tables 3.42, 3.43, 3.44, 3.45). Numerical differences were small at Cell 16; at Cell 18 vegetated patches had higher upper layer exchangeable calcium, CEC and TEC. SE dump vegetated patches had higher lower layer exchangeable calcium, TEC and CEC than bare patches; despite differences in averages and medians, ranges overlapped substantially, explaining the lack of significant differences.

4.3.4 EC and pH

W1 dump upper and lower layer pH at bare and vegetated patches on LFH mineral soil mix did not differ significantly (Tables 3.34, 3.35). EC was not analyzed and showed no trends. Cover soil depth effects were not significant on pH, with no trends for EC. Patches did not differ significantly on LFH mineral soil mix in upper or lower layer pH and EC at SE dump or in upper layer pH or lower layer EC at MLSB (Tables 3.36, 3.37, 3.38, 3.39). There were no numerical differences in lower layer pH or upper layer EC at MLSB (Tables 3.37, 3.39).

Upper layer pH was significantly higher on bare than vegetated patches on peat mineral soil mix at W1 dump; there was no difference in lower layer (Tables 3.40, 3.41). There were no significant or numerical differences in upper or lower layer pH on peat mineral soil mix at SE dump or MLSB (Tables 3.42, 3.43, 3.44, 3.45). No statistical tests were run for W1 dump EC (Tables 3.40, 3.41). Two thirds of bare quadrats had higher upper layer and lower layer EC than vegetated but differences were small. There were no significant differences in upper or lower layer EC on peat mineral soil mix at SE dump or MLSB; SE dump bare patches had numerically higher EC for both layers (Tables 3.42, 3.43, 3.44, 3.45).

4.3.5 Texture

Upper layer texture at both patch types was the same in 14 of 32 pairs; 18 pairs had the same lower layer texture. Vegetated patches had significantly higher upper layer silt, bare patches had significantly higher upper layer clay and there were no differences in lower layer sand, silt or clay (Tables 3.24, 3.25, 3.46). There were no significant differences related to cover soil depth. Texture classes on bare and vegetated patches were significantly different. Upper layer bare patches were clay loam textured and vegetated were loam (Tables 3.24, 3.25).

At SE dump 5 of 7 pairs on LFH mineral soil mix had the same upper layer texture at bare and vegetated patches; 4 of 7 pairs had the same lower layer texture. Upper and lower layer sand, silt and clay content did not differ significantly for bare and vegetated patches (Tables 3.28, 3.47). Average upper and lower layer texture for bare and vegetated patches was loam.

At MLSB, 7 of 10 pairs on LFH mineral soil mix had the same upper layer texture at bare and vegetated patches and 6 had the same lower layer texture. Bare patches had significantly higher upper layer clay than vegetated patches (Tables 3.30, 3.31). Cell 16 upper layer silt was numerically higher at vegetated than bare patches, with little difference at Cell 18. Average texture on bare and vegetated patches for upper and lower layers was clay loam (Tables 3.30, 3.31, 3.48).

On peat mineral soil mix at W1 dump, 21 of 34 pairs had the same upper layer texture at bare and vegetated patches and 22 had the same lower layer texture. Upper layer silt content was significantly higher on vegetated patches; clay content was significantly higher on bare patches with no significant cover soil application depths effects (Tables 3.26, 3.27). Average upper and lower layer texture of bare and vegetated patches was clay loam (Tables 3.26, 3.27, 3.49).

At SE dump 7 of 10 pairs had the same upper layer texture on bare and vegetated patches on peat mineral soil mix; 3 of 9 pairs had the same lower layer texture. Upper or lower layer sand, silt or clay content between bare and vegetated patches did not differ significantly (Tables 3.29, 3.47). Vegetated patches had slightly higher lower layer sand and less silt than bare patches, resulting in sandy loam lower layer texture on vegetated patches and loam on bare patches; upper layer texture was the same for vegetated and bare patches.

On peat mineral soil mix at MLSB, 5 of 8 pairs had the same upper layer texture at bare and vegetated patches; 3 of 8 had matching lower layer textures. Upper layer silt and clay and lower layer sand did not differ significantly between bare and vegetated patches; upper layer sand, lower layer silt and lower layer clay could not be analyzed due to non homogeneity (Tables 3.32, 3.33, 3.50). There was a 5 % difference in upper layer sand at Cell 16; ranges at bare and vegetated patches did not overlap, with no difference in upper layer sand content at Cell 18. Only two samples were collected at Cell 16 making it difficult to draw conclusions. There was a 4 % difference in average lower layer clay between bare and vegetated patches at Cell 18 but medians were similar, likely indicating no difference. Lower layer silt was similar on vegetated and bare patches. Average texture of the upper layer at bare and vegetated patches was sandy loam at Cell 16 and clay at Cell 18 (Tables 3.32, 3.33). Cell 16 lower layer texture was clay at bare patches and clay loam at vegetated patches (Table 3.50). Cell 18 lower layer texture was sandy clay loam at bare and vegetated patches.

4.3.6 Water retention and volumetric water content

W1 dump vegetated patches had significantly higher upper layer water retention at 10 kPa (0.1 bar), 30 kPa (0.3 bar; field capacity) and 1500 kPa (15 bar; wilting point) and water holding capacity than bare patches on LFH mineral soil mix; cover soil depth was not a factor (Tables 3.24, 3.25). Water retention or water holding capacity did not differ significantly for bare and vegetated patches on LFH mineral soil mix at SE dump or MLSB (Tables 3.28, 3.30, 3.31). SE dump vegetated patches on LFH mineral soil mix had higher average and median water retention at 10 and 30 kPa than bare patches; ranges overlapped explaining lack of significant differences. MLSB values were higher at vegetated patches. W1 dump surface soil volumetric water content at bare and vegetated patches was similar (Tables 3.24, 3.25). SE dump had insufficient samples for analysis; numerically neither bare nor vegetated patches consistently had higher surface soil water content (Table 3.28). MLSB surface soil volumetric water content did not differ significantly between bare and vegetated patches on LFH mineral soil mix (Tables 3.30, 3.31).

W1 dump peat mineral soil mix vegetated patches had significantly higher upper layer water retention at 10, 30 and 1500 kPa and water holding capacity than bare patches (Tables 3.26, 3.27). Cover soil depth had no significant effect. Vegetated patches had double values of bare. SE dump and MLSB had no significant differences on bare and vegetated patches on peat mineral soil mix in upper layer water retention at 10, 30 or 1500 kPa, nor in water holding capacity (Tables 3.29, 3.32, 3.33). Most pairs at SE dump were higher at vegetated patches but averages were less different. Differences on bare and vegetated patches on peat mineral soil mix were pronounced at Cell 18; Cell 16 values differed by a few percent. W1 dump surface soil volumetric water content at bare and vegetated patches was nearly identical (Tables 3.26, 3.27); there were no significant differences on peat mineral soil mix at SE dump or MLSB (Tables 3.29, 3.32, 3.33).

4.3.7 Bulk density and penetration resistance

W1 dump surface bulk density on LFH mineral soil mix bare patches was significantly higher than on vegetated patches and unaffected by cover soil application depth (Tables 3.24, 3.25). There were insufficient samples for statistical analysis of bulk density for bare and vegetated patches on LFH mineral soil mix at SE dump but numerically neither were higher (Table 3.28). Surface soil bulk density did not differ significantly between bare and vegetated patches on LFH mineral soil mix at MLSB; it was numerically higher on bare than vegetated patches (Tables 3.30, 3.31). Vegetated and bare patches did not differ significantly in maximum penetration resistance at W1 dump or MLSB (Tables 3.51, 3.52). Depth at which maximum penetration resistance occurred did not differ significantly. No significant differences were associated with cover soil depth at W1 dump. At MLSB differences between bare and vegetated patches were more pronounced at Cell 16 than Cell 18.

W1 dump bare patches on peat mineral soil mix had significantly higher surface bulk densities than vegetated patches; there was no cover soil application depth effect (Tables 3.26, 3.27). Surface soil bulk density did not differ significantly between bare and vegetated patches on peat mineral soil mix at SE dump or at MLSB (Tables 3.29, 3.32, 3.33). SE dump bare patches had numerically higher bulk densities than vegetated patches. Only one sample from each patch type was collected at Cell 16 and bulk densities were lower than all samples at Cell 18. When data from both sites were pooled the average was skewed downwards such that bare and vegetated patches were almost identical. Cell 18 bulk density on bare patches was higher than on vegetated patches. Maximum penetration resistance was not significantly different at bare and vegetated patches at W1 dump or MLSB (Tables 3.53, 3.54). There was a significant difference in depth of maximum penetration resistance at W1 dump but not MLSB. There was no significant cover soil application depth effect at W1 dump.

4.4 Soil – Vegetation Correlations At Bare And Vegetated Patches

Fewer correlations between soil and vegetation than expected were found at W1 dump at bare and vegetated patches on both cover soils given the large number of significant differences in soil properties between patch types (Tables B.7, B.8, B.9). Many more correlations than expected were found for bare and vegetated patches at SE dump and MLSB (Tables B10, B.11, B.12, B.13, B.14, B.15, B.16, B.17, B.18, B.19). Sample size may have been a factor as more correlations were found at sites with smaller sample sizes. The large number of correlations complicates identification of interesting trends. Few significant correlations, occurred on more than one site on the same cover soil and patch type. More common correlations on the same patch type across sites were expected. Soil-vegetation relationships were site specific, likely indicating soil properties were different at each site even for the same cover soil.

For bare patches on LFH mineral soil mix, the only meaningful correlation on more than one site was positive between upper layer sand and native species richness at SE dump and Cell 18. On vegetated patches on LFH mineral soil mix forb cover was positively correlated with upper layer OM, TOC and TC and with water retention at wilting point (15 bar) at W1 dump and Cell 18. At SE dump and Cell 18 total and native cover were negatively correlated with upper layer clay, and shrub cover with lower layer clay. Moss cover was correlated with upper layer clay and native species richness with lower layer sand at these sites; the relationship was positive at Cell 18 and negative at SE dump. On bare patches on peat mineral soil mix native species cover was positively correlated with litter cover and negatively correlated with bare ground at W1 dump and Cell 18. Native species richness was positively correlated with litter cover and negatively correlated with bare ground at SE dump and Cell 18. There were several correlations at SE dump and Cell 18 including positive correlations between species richness and lower layer CEC; native species richness and lower layer CEC; and forb cover and lower layer silt. Negative correlations at these sites included native species cover and upper layer EC and forb cover and lower layer sand. On vegetated patches on peat mineral soil mix, lower layer C:N ratio was positively correlated with non-native species cover at SE dump and Cell 18.

On both cover soils at all sites different correlations were found at bare and vegetated patches, meaning vegetation was responding to different properties at vegetated and bare patches. There was no obvious difference between bare and vegetated patches in the types of soil properties correlated with vegetation; there were correlations with soil chemical and physical properties for both patch types.

Correlations on bare and vegetated patches on LFH mineral soil mix included a negative correlation between lower layer clay and shrub cover at SE dump, a positive correlation between forb cover and upper layer OM, TOC and TC at Cell 18, a negative correlation between upper layer ESP and native species richness at Cell 18, and a positive correlation between native species richness and lower layer sand at Cell 18. Total and native cover were correlated with lower layer silt at Cell 18, positively on vegetated patches and negatively on bare patches.

Correlations on bare and vegetated patches on peat mineral soil mix included a negative correlation between upper layer sand and live vegetation cover and negative correlations between both upper layer EC and lower layer C:N with native species cover at Cell 18. At W1 dump litter cover was positively correlated with total cover and native cover on bare patches, while on vegetated patches they were negatively correlated. A contradictory correlation also occurred at SE dump; on bare patches lower layer C:N ratio was negatively correlated with non-native species cover while on vegetated patches it was positive.

There were just as many significant correlations on LFH mineral soil mix as on peat mineral soil mix, and they were of similar strength. A few correlations were significant for both cover soils, but most were cover soil specific. Cover soils were expected to have different soil properties so correlation differences were expected. At W1 dump the only correlation common to bare patches on both cover soils was the negative correlation of bare ground with native species cover. At SE dump, total and forb cover were positively correlated with upper layer exchangeable sodium at bare patches on LFH mineral soil mix, but negatively correlated with upper layer exchangeable sodium at bare patches on peat mineral soil mix. Native species richness was negatively correlated with exchangeable calcium, TEC and CEC at bare patches on LFH mineral soil mix but these correlations were positive on peat mineral soil mix. For vegetated patches at SE dump no correlations were repeated on cover soils. At Cell 18 upper layer sand was positively correlated with ground vegetation cover on LFH mineral soil mix but negatively correlated on peat mineral soil mix. The lower layer clay and ground vegetation cover correlation was negative on LFH mineral soil mix but positive on peat mineral soil mix. There were no meaningful shared correlations for vegetated patches at Cell 18.

Slope percent was only correlated with vegetation at bare patches on peat mineral soil mix at SE dump (Table B.20). Slope percent was moderately, positively correlated with bare ground. Ground vegetation cover and total cover were moderately, negatively correlated with slope percent; species richness and native species richness were weakly, negatively correlated with slope percent.

4.5 Changes In Soil Properties At Bare And Vegetated Patches

W1 dump had significant differences between initial soil conditions and soil properties of bare and vegetated patches on LFH mineral soil mix in year 8. Upper layer OM, TOC and TN differed significantly between initial conditions and bare patches but not initial conditions and vegetated patches (Table 3.55). Bare patches had significantly lower upper layer OM, TOC and TN than initial conditions. Bare and vegetated patches had significantly higher upper layer pH than initial conditions on 10 cm LFH mineral soil mix. On 20 cm LFH mineral soil mix pH differed significantly between initial conditions and vegetated patches; pH at bare patches and initial conditions were numerically different with unequal variances masking significance. Initial pH of vegetated patches could be rated good while pH of bare patches would be fair (Alberta Soils Advisory Committee 1987). There were likely no numerical differences in upper layer texture between year 1 and bare and vegetated patches in year 8. Upper layer texture was clay loam or loam on LFH mineral soil mix in years 1 and 8 at both patch types.

Soil properties between initial conditions and bare and vegetated patches were significantly different on peat mineral soil mix in year 8 at W1 dump. On 10 cm peat mineral soil mix vegetated patches had significantly greater upper layer TOC and OM than initial conditions and initial upper layer TOC and OM were significantly greater than at bare patches (Table 3.56). On 20 cm peat mineral soil mix initial upper layer OM and TOC were significantly greater than on bare patches, with no significant difference between initial conditions and vegetated patches due to large standard errors. On 10 and 20 cm peat mineral soil mix initial upper layer TN was significantly greater than at bare patches but not at vegetated patches. Trends in pH were difficult to interpret. Bare and vegetated patches had significantly higher upper layer pH than initial conditions on 10 cm peat mineral soil mix. On the 20 cm only bare patches had significantly higher pH than initial conditions. Upper layer texture on peat mineral soil mix in years 1 and 8 on bare and vegetated patches was mostly clay loam; some upper layer samples were loam but clay was just below the threshold for clay loam.

5. DISCUSSION

5.1 Soil Quality At Bare And Vegetated Patches

Largest and most distinct bare patches at W1 dump were associated with the most significant differences between bare and vegetated patches for many soil chemical and physical properties. Many of these significant differences in soil properties led to differences in soil quality at W1 dump, while at SE dump and MLSB soil quality was generally similar at bare and vegetated patches.

Bare patches on LFH mineral soil mix at W1 dump had poor upper layer soil quality due to TOC, C:N, CEC, texture and water holding capacity (Table 3.57). Upper layer TOC on bare patches was below or just above the 2 % threshold between good and fair ratings for topsoil in the plains region (Alberta Soils Advisory Committee 1987), respectively, while upper layer TOC on vegetated patches was well above the threshold and rated good. OM and TC are closely tied to TOC, making them less than ideal on bare patches. C:N ratio is an important indicator of soil nitrogen supply for plants. At C:N ratios $\geq$ 25:1 nitrogen immobilization by soil microorganisms occurs, depleting the supply of soil nitrogen for plants (Brady and Weil 2004). Upper layer C:N at vegetated patches was just below this threshold and much higher on bare patches.

There are no defined criteria for exchangeable cations, but some general guidelines for CEC. Values < 5 meq / 100 g are considered low, 5 to 30 meq /

100 g is medium and > 30 meq / 100 g is high (Naeth 2009). These guidelines are not forest specific but provide some context for plant responses. Bare and vegetated patches had medium upper layer CEC but vegetated patches were at the upper end, providing a larger supply of cations for plants (Table 3.57).

Upper layer texture was clay loam for bare patches and loam for vegetated patches. Bare patch texture could be rated fair and vegetated patch texture good (Alberta Soils Advisory Committee 1987) (Table 3.57). It was difficult to assess soil quality based on water retention and water holding capacity because it was difficult to define an optimal field capacity or wilting point and there is no critical threshold that defines minimum water holding capacity for plant growth. Any significant increase in water holding capacity may represent a benefit for plants meaning vegetated patches have superior water holding properties, which in a dry year like 2011 could have been critical for plants.

Despite significant differences, bare and vegetated patches were rated similarly for lower layer TOC, upper layer base saturation and surface bulk density on LFH mineral soil mix at W1 dump (Tables 3.57, 3.58). Lower layer TOC at bare and vegetated patches was < the 2 % threshold for a good rating (Alberta Soils Advisory Committee 1987). At such low concentrations any increase would help. Base saturation, representing degree to which the exchange capacity is occupied by base cations, gives an indication of base cations a soil can provide to plants (Havlin et al. 2005). It can be difficult to interpret because the base saturation and cation availability relationship is modified by soil colloids. Soil with more OM or 1:1 clays can provide more cations at lower base saturations than soil with 2:1 clays. Upper layer base saturation at bare and vegetated patches was > 100 %, indicating there was no limitation related to base cation availability. Bulk densities > 1.6 g / cm^3 may negatively affect root growth for loam and clay loam soils (USDA 2001). Average bulk densities on bare and vegetated patches were below this threshold, meaning neither were overly compacted. Elevated bulk densities can reduce water infiltration (Brady and Weil 2004); while there is no defined threshold, the difference in bulk density may be great enough to reduce infiltration at bare versus vegetated patches. On the other end of the spectrum low bulk densites can result in reduced plant yield likely due to reduced root to soil contact and nutrient uptake (Arvidsson 1999, Håkansson 1990). Arvidsson

(1999) saw reduced yields at 1.14 g / cm^3 bulk density in mineral soils with 4 % OM. The threshold for organic soils is unclear. Vegetated patches had lower bulk density than bare patches, which did not appear to be limiting plant growth.

W1 dump peat mineral soil mix at vegetated patches had better soil quality than bare patches due to upper layer pH and CEC, lower layer TOC and water holding properties (Tables 3.59, 3.60). Average upper layer pH on bare patches was rated poor on 10 cm and fair on 20 cm peat mineral soil mix while on vegetated patches upper layer pH was rated fair on 10 cm and good on 20 cm peat mineral soil mix (Alberta Soils Advisory Committee 1987). As soil quality criteria suggest, this difference will likely be felt most strongly by conifer tree species as they prefer soils with lower pH; other species may be more tolerant to a wider pH range. Conifers are a major part of the desired plant communities on these reclaimed sites which makes this an important issue. Vegetated patches had high upper layer CEC and bare patches had medium (Naeth 2009). Average lower layer TOC at vegetated patches on 20 cm peat mineral soil mix exceeded 2 % and was rated good while average lower layer TOC on bare patches was below 2 % and rated fair; ratings were the same on 10 cm. Upper layer TOC was more difficult to interpret. While values were rated good at bare and vegetated patches, the substantial magnitude of the difference might be important for plant growth. Similarly, the magnitude of differences in water retention and water holding capacity between bare and vegetated patches is likely large enough that vegetated patches were more able to hold water than bare patches but there are no defined criteria for these parameters to validate this finding.

Statistical differences in upper layer silt and clay, lower layer base saturation and surface bulk density on peat mineral soil mix at W1 dump may not have soil quality implications (Tables 3.59, 3.60). Average upper layer texture was clay loam for both patch types regardless of significant differences in silt and clay. Lower layer base saturation was well over 100 % at both bare and vegetated patches meaning there likely was no limitation in base cation availability. Surface bulk density was below the threshold for negative effects on root growth (USDA 2001) for both patch types suggesting neither were limited by compaction. The effect of the difference in bulk density on infiltration is less clear. It is possible that infiltration is lower at bare than vegetated patches.

Bare and vegetated patches on both soil covers at W1 dump were not limited by salinity or sodicity (Tables 3.57, 3.58, 3.59, 3.60). The threshold value between good and fair ratings for salinity (EC) is 2 dS / m for surface material and 3 dS / m for subsurface material (Alberta Soils Advisory Committee 1987). At an EC of 2 dS / m some plants may be negatively affected although most are not affected until EC reaches 4 dS / m (Brady and Weil 2004). Upper and lower EC did surpass these thresholds at some bare and vegetated patches on both cover soils; this tended to occur in hot spots on the landscape, and both patch types at a pair had elevated EC. However, average values for bare and vegetated patches were well below 2 dS / m and soil at both was rated good. The critical level for ESP is 15 %, beyond which soil is sodic and sodium occupies enough exchange sites to have negative effects on soil structure and physical properties (Brady and Weil 2004). Average values on bare and vegetated patches on both cover soils at W1 dump were well below this. The same pairs with distinctly high ECs for both patches had much higher exchangeable sodium and ESP than the other pairs. ESP of some layers at these pairs exceeded 15 %. It is not clear whether this was the dominant factor explaining vegetation growth at those pairs.

Maximum penetration resistance at bare and vegetated patches on both covers at W1 dump exceeded the threshold beyond which plant growth is negatively affected (2 MPa), although critical values are plant species specific and as high as 5 MPa in some situations (Naeth et al. 1991, Dexter and Zoebisch 2006, Mari and Changying 2008) (Tables 3.57, 3.59). On peat mineral soil mix, depth of maximum resistance was greater for vegetated (23 to 25 cm) than bare patches (18 to 22 cm), meaning higher penetration resistance was closer to the surface for bare patches, which may have impacted roots. Penetration resistance seems to have had no effect on vegetation on LFH mineral soil mix.

Penetration resistance on both cover soils at W1 dump were higher than 2005 values (six years earlier) (Mackenzie 2006, Mackenzie and Naeth 2010). This may be due to soil water conditions at the time of measurement. Precipitation was much lower in 2011 than 2005 which would have resulted in lower soil water contents and increased penetration resistance. The penetrometer stopped working not long after measurements at W1 dump were conducted which could indicate data collected were not accurate. Despite this potential issue, data were likely precise and thus comparable between bare and vegetated patches. Soil water differences between bare and diverse patches were very minor which also validates comparisions between patch types.

There were no differences in soil quality with the possible exception of lower layer TOC between bare and vegetated patches on LFH mineral soil mix at SE dump (Tables 3.61, 3.62). Lower layer TOC was rated fair at bare patches and good at vegetated patches. Both bare and vegetated patches had C:N ratios exceeding 25:1 meaning both were similarly limited by soil nitrogen as it was immobilized by soil microorganisms. Otherwise soil quality was adequate and there were no limitations due to salinity, sodicity, acidity, alkalinity or compaction.

Soil quality of bare and vegetated patches on peat mineral soil mix at SE dump did not differ except in upper layer EC (Tables 3.63, 3.64). While there was no statistically significant difference, upper layer EC was > 2 dS / m at bare patches and < 2 dS / m at vegetated patches, the threshold between good and fair ratings for surface material (Alberta Soils Advisory Committee 1987). Otherwise soil quality of both patch types was fair to good and the only limitation was C:N ratio which exceeded the 25:1 threshold at which nitrogen immobilization occurs.

MLSB had few differences in soil properties between bare and vegetated patches but many trends differed at Cells 16 and 18. Although the same LFH mineral soil mix material was used at Cells 16 and 18, it was applied to a different substrate at Cell 16 which may explain the differences. Bare and vegetated patches may have differed in soil quality (Tables 3.65, 3.66) but sample size was so small it is difficult to be confident in these findings. For example, upper and lower layer TOC at vegetated patches was above the 2 % threshold (Alberta Soils Advisory Committee 1987) while at bare patches upper and lower layer TOC were just above and below 2 %, respectively. C:N ratio at bare patches at Cell 16 was well above 25:1 while at vegetated patches it was below this immobilization threshold. There was one soil property difference at MLSB that was statistically significant but did yield a difference in soil quality. Bare patches had significantly higher upper layer clay but both patches had the same average texture class (clay loam). Bare and vegetated patches had similar soil quality for most other chemical and physical properties. There might be some cause for concern in penetration resistance and pH for both patch types.

On peat mineral soil mix at Cell 18 some differences in soil quality may not have been captured by statistical analysis with combined Cells 16 and 18 due to low sample size (Tables 3.67, 3.68). For example, upper layer C:N at bare patches at one Cell 18 block was above the threshold for nitrogen immobilization; at vegetated patches it was lower (Brady and Weil 2004). Cell 18 upper layer CEC was medium on bare patches and high at vegetated patches; at Cell 16 it was rated high at bare and vegetated patches. Overall soil quality at both patch types at Cells 16 and 18 was generally good with the exception of high penetration resistances, poor pHs at bare and vegetated patches at Cell 16, poor upper layer texture at Cell 18 and poor lower layer texture at Cell 16.

These results are quite different than those of Naeth et al. (2011) who studied the differences in soil chemical and physical properties between areas of high and low vegetation cover on peat mineral soil mix at the South West Sand Storage Facility at Syncrude's base mine. In the upper 10 cm there were significant differences in sodium adsorption ratio and soluble sodium between areas of high and low vegetation. There were no significant differences in organic carbon, organic matter, pH, electrical conductivity, saturation, soluble cations and anions, available nutrients, extractable micronutrients or particle size fractions. Total carbon and nitrogen, exchangeable cations, and penetration resistance, water retention and bulk density were not reported in this study.

The underlying reason for significant differences in soil properties at W1 dump on both cover soils was likely lack of cover soil at many bare patches, or cover soil at bare patches was often mixed with secondary material or was buried beneath a layer of mineral material. There were some difficulties with cover soil application at W1 dump (frozen lumps that were difficult to spread uniformly, admixing) and the bare patches seem to be the result of these difficulties. This conclusion is reinforced by the lack of significant differences at SE dump and MLSB, where there were no significant differences in cover soil depth.

5.2 Vegetation At Bare And Vegetated Patches

Vegetation at bare and vegetated patches differed at all sites regardless of significant differences in soil chemical and physical properties. Productivity was severely impacted at bare patches, and while there was a similar number of non-native species at bare and vegetated patches, their cover was proportionally higher at bare patches on peat mineral soil mix at all sites and on LFH mineral soil mix at SE dump and Cell 16. This could indicate bare patches, where there is less competition, provide a place for non-native species to develop which could result in their expansion into surrounding native vegetation. Vegetated patches had a higher proportion of shrub cover than bare patches on LFH mineral soil mix at all three sites and on peat mineral soil mix at SE dump and W1 dump. This trend was not seen with any other growth form type. Unlike non-native species cover which was impacted by biotic interactions, shrub cover was likely higher in vegetated patches due to differences in conditions relative to bare areas.

5.3 Changes In Soil Properties Over Time At Bare And Vegetated Patches

On 10 and 20 cm LFH mineral soil mix and 20 cm peat mineral soil mix upper layer OM, TOC and TN had not increased at vegetated patches relative to initial conditions as expected due to additions from plant residues; increases were observed on 10 cm peat mineral soil mix. Bare patches on both cover soils had significantly lower upper layer OM, TOC and TN than initial conditions. This decline can likely be explained by microbial decomposition of any organic material that was present initially in 2004. Microbial decomposition may also explain why there was no increase in OM, TOC and TC at vegetated patches; additions were balanced by increased microbial decomposition. . There was a consistent increase in pH in year 8; it was rated fair on most bare and vegetated patches on both cover soils while initial pH was rated good (Alberta Soils Advisory Committee 1987).

6. CONCLUSIONS

Bare patches at the 8 year old site resulted from sub-optimal soil conditions due to lack of cover soil through uneven application. On LFH mineral soil mix bare patches were more related to deficiencies in plant growth essentials (carbon, nitrogen, exchangeable cations, water holding capacity) than to surpluses in plant growth inhibitors or poor soil quality (salinity, sodicity, compaction). On peat mineral soil mix plants were also limited by shortages in exchangeable cations and water holding capacity, and there could have been negative effects from high pH and increased penetration resistance. At 4 and 13 year old sites bare patches were generally smaller and did not have significantly less cover soil than nearby densely vegetated patches; no studied parameters explain their bare patches.

Soil OM, TOC and TN at bare patches on both cover soils at W1 dump were significantly lower than in the first year after reclamation when vegetation was just beginning to develop; soil OM, TOC and TN on vegetated patches had not changed significantly. In contrast, pH was significantly higher on both bare and vegetated patches in year 8 than in year 1.

Vegetation at bare patches was not consistent across sites or cover soils. Differences in dominant growth forms and quadrat level species richness were observed; there were no trees at any bare patches. Vegetated patches had higher quadrat level species richness and native species richness than bare patches on both cover soils at all sites; quadrat non-native species richness was similar on both patch types. However, bare patches on peat mineral soil mix at all three sites and on LFH mineral soil mix at two sites had a higher proportion of non-native species cover than vegetated patches. Vegetated patches on LFH mineral soil mix at all three sites and on peat mineral soil mix at two sites had a higher proportion of shrub cover than bare patches.

7. LITERATURE CITED

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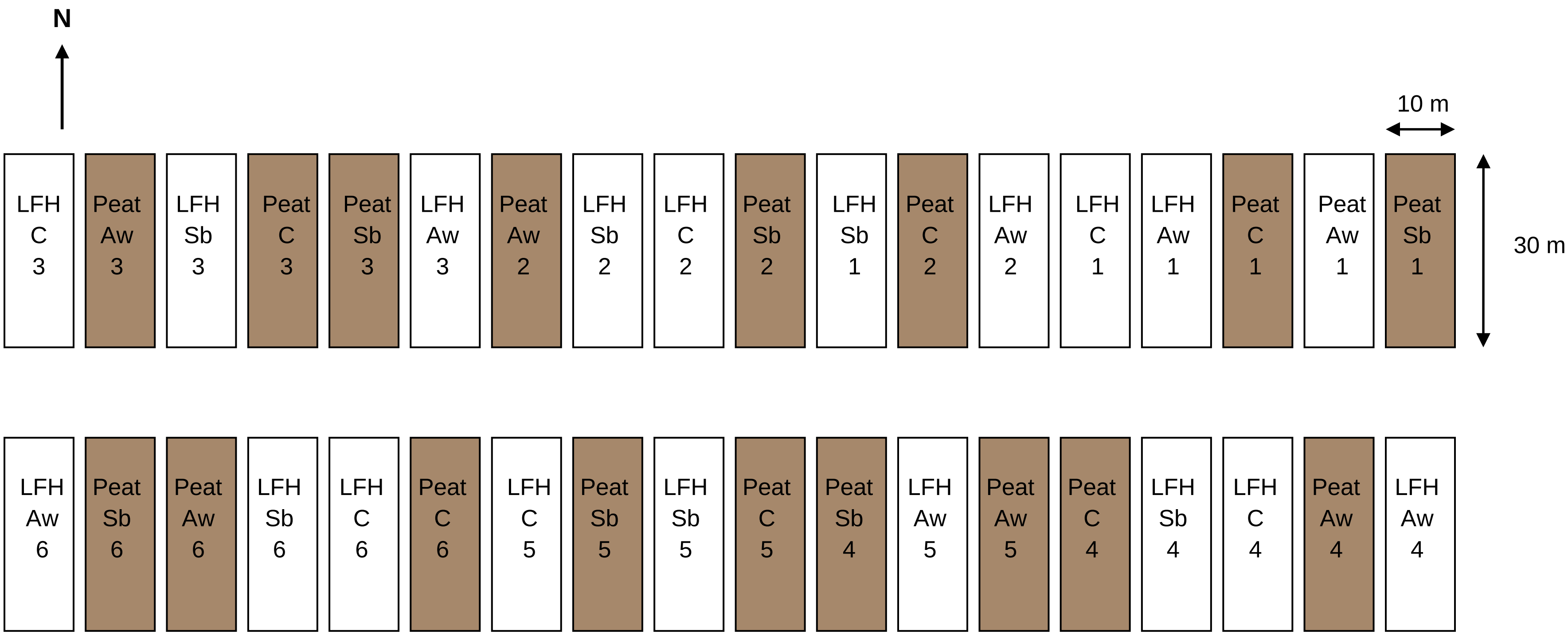

Figure 3.1. Research plot layout at SE dump. White plots have LFH-mineral mix; brown plots have peat-mineral mix. Woody debris type is designated as Sb = *Picea mariana,* Aw = *Populus tremuloides*, C = control with no woody debris. Numbers denote treatment replicates.

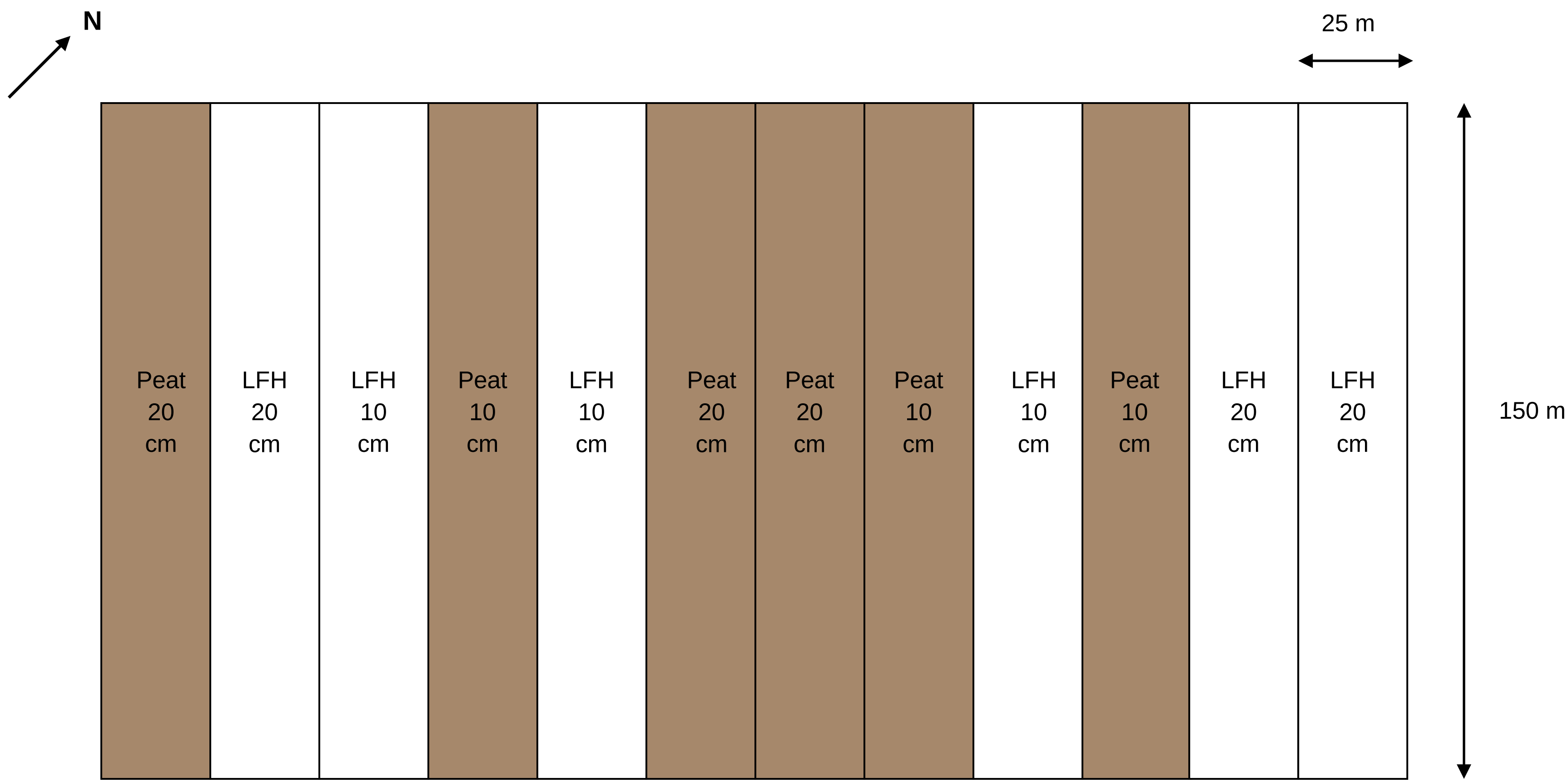

Figure 3.2. Research plot layout at W1 dump. White plots are LFH mineral soil mix which was applied at 10 cm and 20 cm depths, brown plots are peat mineral soil mix which was applied at 10 cm and 20 cm depths. There are three replicates of each cover soil – application depth combination.

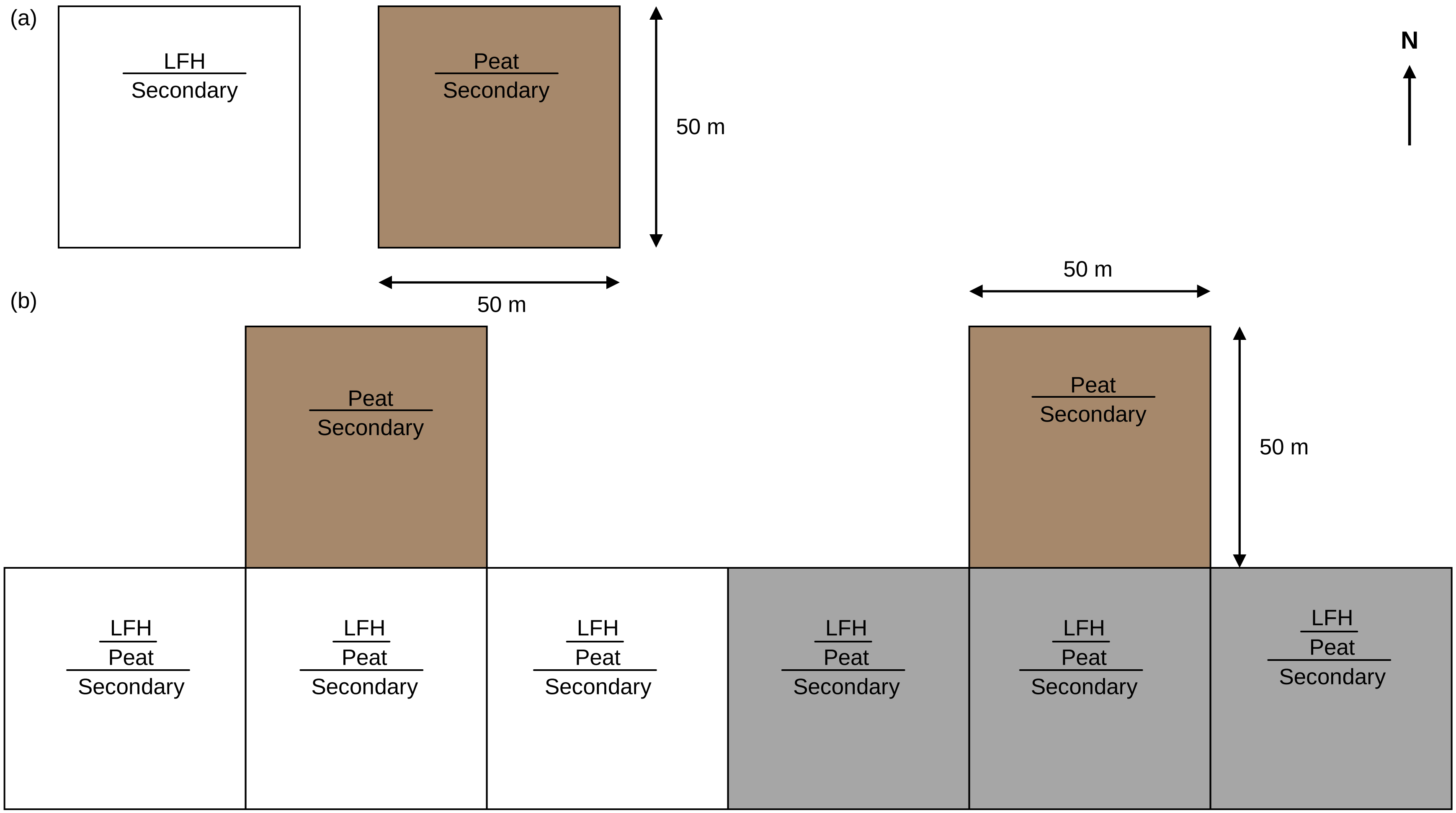

Figure 3.3. Research plot layout at MLSB; (a) Cell 16, (b) Cell 18. White plots are LFH mineral soil mix with winter placement; gray plots are LFH mineral soil mix with summer placement; brown plots are peat mineral soil mix.

Table 3.1. Treatment information at three study sites.

Site	Age	Substrate	Cover soil	LFH type
SE dump	4	B/C horizon	20 cm LFH mineral soil mix	*Populus tremuloides, Picea glauca*
	4	Overburden	30 cm peat mineral soil mix	
W1 dump	8	Secondary	10 cm LFH mineral soil mix	*Populus tremuloides*
	8	Secondary	20 cm LFH mineral soil mix	*Populus tremuloides*
	8	Secondary	10 cm peat mineral soil mix	
	8	Secondary	20 cm peat mineral soil mix	
MLSB Cell 16	13	Secondary	18 cm LFH mineral soil mix	*Populus tremuloides*
	13	Secondary	18 cm peat mineral soil mix	
MLSB Cell 18	13	Peat mineral soil mix over secondary	12 cm LFH mineral soil mix	*Populus tremuloides*
	13	Secondary	18 cm peat mineral soil mix	

Age at time of paired sampling in 2011.
LFH type refers to donor site vegetation.
Secondary is fine textured, non-saline and non-sodic material from either suitable upland soil or surficial geologic material salvaged to a depth not considered suitable for plants.

Table 3.2. Soil parameters and analytical methods.

Soil parameter	Analytical method	Reference
Hydrogen ion activity (pH)	Saturated paste (with water)	Miller and Curtin 2008
Electrical conductivity	Saturated paste (with water)	Miller and Curtin 2008
Total organic carbon	Dry combustion	Nelson and Sommers 1996
Total inorganic carbon	Dry combustion	Nelson and Sommers 1996
Total carbon	Dry combustion	Nelson and Sommers 1996
Total nitrogen	Dry combustion	Bremner 1996
C:N ratio	Calculation	
Organic matter	Calculation	Nelson and Sommers 1992
Cation exchange capacity	Extraction with ammonium acetate at pH 7	McKeague 1978
Total exchange capacity (TEC)	Extraction with ammonium acetate at pH 7	McKeague 1978
Exchangeable cations (Ca, Mg, Na, K)	Extraction with ammonium acetate at pH 7	McKeague 1978
Exchangeable sodium percentage	Extraction with ammonium acetate at pH 7	McKeague 1978
Base saturation	Extraction with ammonium acetate at pH 7	McKeague 1978
Sand, silt and clay; texture	Hydrometer method	Kroetsch and Wang 2008
Water repellency	Molarity ethanol droplet method	Yeung 1990

Table 3.3. Hydrophobicity of surface soil at selected bare ground quadrats at three sites.

Site	Cover soil treatment	Cover soil replicate	Quadrat	Molarity ethanol droplet value	Water repellency rating
W1 dump	10 cm LFH mineral soil mix	1	3	0.3	Low
W1 dump	20 cm LFH mineral soil mix	1	5	0.3	Low
W1 dump	10 cm peat mineral soil mix	1	4	0.2	Low
W1 dump	20 cm peat mineral soil mix	1	5	0.3	Low
SE dump	Peat mineral soil mix	6	3	0.4	Low
Cell 16	LFH mineral soil mix	1	1	0.3	Low
Cell 18	LFH mineral soil mix	4	1	0.3	Low
Cell 18	Peat mineral soil mix	2	2	0.3	Low

Table 3.4. Vegetation parameters at bare and vegetated patches on LFH mineral soil mix at W1 dump eight years after reclamation.

	Bare			Vegetated		
	Mean	Median	Range	Mean	Median	Range
Bare ground (%)	88.9	92.0	48.0 - 98.0	0.6	0.0	0.0 - 7.0
Litter (%)	8.3	5.5	1.0 - 50.0	86.5	88.5	69.0 - 98.0
Ground live vegetation (%)	0.8	1.0	0.0 - 6.0	5.8	4.0	1.0 - 22.0
Quadrat species richness	3.1	3.0	1.0 - 9.0	9.5	9.5	6.0 - 13.0
Quadrat native richness	2.7	3.0	0.0 - 6.0	8.4	9.0	5.0 - 12.0
Quadrat non-native richness	0.5	0.0	0.0 - 3.0	1.2	1.0	0.0 - 3.0
Woody plant density (plants / m^2)	1.2	0.0	0.0 - 10.0	21.0	20.0	0.0 - 50.0

10 and 20 cm LFH mineral soil mix data were pooled for a total of 42 quadrats (including those not soil sampled) for each patch type.

Table 3.5. Vegetation parameters at bare and vegetated patches on LFH mineral soil mix at SE dump four years after reclamation.

	Bare			Vegetated		
	Mean	Median	Range	Mean	Median	Range
Bare ground (%)	62.4	70.0	25.0 - 96.0	0.0	0.0	0.0 - 0.0
Litter (%)	31.4	25.0	2.0 - 68.0	94.9	94.0	93.0 - 97.1
Ground live vegetation (%)	2.0	2.0	0.0 - 4.0	3.1	3.0	2.0 - 5.0
Quadrat species richness	7.6	7.0	6.0 - 10.0	9.7	10.0	7.0 - 11.0
Quadrat native richness	5.7	5.0	4.0 - 8.0	7.4	8.0	6.0 - 9.0
Quadrat non-native richness	1.9	2.0	1.0 - 3.0	2.3	2.0	1.0 - 3.0
Woody plant density (plants / m^2)	4.3	0.0	0.0 - 20.0	28.6	30.0	10.0 - 60.0

There were 7 pairs of quadrats within three replicates of the cover soil treatment.

Table 3.6. Vegetation parameters at bare and vegetated patches on LFH mineral soil mix at two sites at MLSB thirteen years after reclamation.

	Bare			Vegetated		
	Mean	Median	Range	Mean	Median	Range
Cell 16						
Bare ground (%)	68.8	86.5	10.0 - 92.0	0.0	0.0	0.0 - 0.0
Litter (%)	28.8	9.5	8.0 - 88.0	96.8	97.0	96.0 - 97.0
Ground live vegetation (%)	0.5	0.5	0.0 - 1.0	3.0	3.0	2.0 - 4.0
Quadrat species richness	2.8	3.0	1.0 - 4.0	7.0	6.5	6.0 - 9.0
Quadrat native richness	1.8	1.5	1.0 - 3.0	5.5	5.5	5.0 - 6.0
Quadrat non-native richness	1.0	1.0	0.0 - 2.0	1.5	1.0	0.0 - 4.0
Woody plant density (plants / m^2)	0.0	0.0	0.0 - 0.0	20.0	20.0	10.0 - 30.0
Cell 18						
Bare ground (%)	31.0	9.0	2.0 - 93.0	0.0	0.0	0.0 - 0.0
Litter (%)	65.5	86.5	4.0 - 94.0	94.8	96.0	89.0 - 97.0
Ground live vegetation (%)	1.3	1.5	0.0 - 2.0	4.3	3.0	1.0 - 11.0
Quadrat species richness	3.5	3.5	2.0 - 5.0	6.7	6.5	5.0 - 8.0
Quadrat native richness	3.2	3.0	2.0 - 5.0	6.0	6.0	5.0 - 7.0
Quadrat non-native richness	0.3	0.0	0.0 - 1.0	0.7	0.5	0.0 - 2.0
Woody plant density (plants / m^2)	0.0	0.0	0.0 - 0.0	26.7	20.0	10.0 - 50.0

There were 4 pairs of quadrats at Cell 16 within one cover soil replicate and there were 6 pairs of quadrats at Cell 18 within three cover soil replicates.

Table 3.7. Vegetation parameters at bare and vegetated patches on peat mineral soil mix at W1 dump eight years after reclamation.

	Bare			Vegetated		
	Mean	Median	Range	Mean	Median	Range
Bare ground (%)	86.0	90.5	8.0 - 99.0	1.9	0.0	0.0 - 13.0
Litter (%)	12.2	8.0	0.0 - 91.0	81.2	84.0	40.0 - 98.0
Ground live vegetation (%)	0.7	1.0	0.0 - 6.0	13.1	7.5	2.0 - 46.0
Quadrat species richness	4.1	4.0	1.0 - 9.0	9.5	9.0	6.0 - 13.0
Quadrat native richness	2.8	3.0	1.0 - 7.0	7.5	7.0	5.0 - 12.0
Quadrat non-native richness	1.4	1.0	0.0 - 3.0	2.0	2.0	0.0 - 4.0
Woody plant density (plants / m^2)	2.1	0.0	0.0 - 20.0	23.6	20.0	0.0 - 130.0

10 and 20 cm peat mineral soil mix data were pooled for a total of 42 quadrats (including those not soil sampled) for each patch type.

Table 3.8. Vegetation parameters at bare and vegetated patches on peat mineral soil mix at SE dump four years after reclamation.

	Bare			Vegetated		
	Mean	Median	Range	Mean	Median	Range
Bare ground (%)	73.4	80.5	40.0 - 94.0	6.1	1.0	0.0 - 32.0
Litter (%)	17.4	11.5	2.0 - 54.0	88.3	93.0	67.0 - 96.0
Ground live vegetation (%)	2.4	3.0	0.0 - 5.0	4.5	5.0	1.0 - 8.0
Quadrat species richness	6.5	6.0	3.0 - 11.0	8.8	9.0	6.0 - 11.0
Quadrat native richness	4.9	5.0	2.0 - 8.0	7.0	7.5	5.0 - 8.0
Quadrat non-native richness	1.6	1.0	1.0 - 4.0	1.8	2.0	1.0 - 3.0
Woody plant density (plants / m^2)	1.0	0.0	0.0 - 10.0	28.0	25.0	10.0 - 80.0

There were 10 pairs of quadrats within three replicates of the cover soil treatment.

Table 3.9. Vegetation parameters at bare and vegetated patches on peat mineral soil mix at two sites at MLSB thirteen years after reclamation.

	Bare			Vegetated		
	Mean	Median	Range	Mean	Median	Range
Cell 16						
Bare ground (%)	88.0	88.0	82.0 - 94.0	0.0	0.0	0.0 - 0.0
Litter (%)	7.0	7.0	4.0 - 10.0	88.5	88.5	84.0 - 93.0
Ground live vegetation (%)	0.5	0.5	0.0 - 1.0	1.5	1.5	1.0 - 2.0
Quadrat species richness	3.5	3.5	3.0 - 4.0	7.0	7.0	7.0 - 7.0
Quadrat native richness	1.5	1.5	1.0 - 2.0	3.5	3.5	3.0 - 4.0
Quadrat non-native richness	2.0	2.0	2.0 - 2.0	3.5	3.5	3.0 - 4.0
Woody plant density (plants / m^2)	0.0	0.0	0.0 - 0.0	5.0	5.0	0.0 - 10.0
Cell 18						
Bare ground (%)	60.3	80.0	7.0 - 98.0	0.5	0.0	0.0 - 2.0
Litter (%)	35.3	13.5	1.0 - 88.0	94.2	96.0	89.0 - 98.0
Ground live vegetation (%)	1.0	1.0	0.0 - 2.0	2.0	2.0	1.0 - 3.0
Quadrat species richness	2.0	2.0	0.0 - 4.0	5.5	5.0	2.0 - 10.0
Quadrat native richness	1.5	1.0	0.0 - 4.0	3.8	4.0	0.0 - 8.0
Quadrat non-native richness	0.5	0.5	0.0 - 1.0	1.7	2.0	1.0 - 2.0
Woody plant density (plants / m^2)	1.7	0.0	0.0 - 10.0	3.3	0.0	0.0 - 20.0

There were 2 pairs of quadrats at Cell 16 within one cover soil replicate and there were 6 pairs of quadrats at Cell 18 within two cover soil replicates.

Table 3.10. Presence (+) and absence (-) of plant species on bare and vegetated patches on LFH mineral soil mix at W1 dump eight years after reclamation.

Species	Bare	Vegetated
Native grasses		
Agropyron trachycaulum (Link) Malte	-	+
Bromus ciliatus L.	-	+
Calamagrostis canadensis (Michx.) Beauv.	-	+
Elymus innovatus Beal	+	+
Poa palustris L.	-	+
Schizachne purpurascens (Torr.) Swallen ssp. *purpurascens* (T.) S.	-	+
Native sedges		
Carex aenea Fern.	-	+
Carex aurea Nutt.	-	+
Carex chordorrhiza L.f.	+	+
Carex sp.	+	+
Native forbs		
Achillea millefolium L.	+	+
Arnica chamissonis Less.	+	+
Aster ciliolatus Lindl.	+	+
Astragalus canadensis L.	-	+
Asteraceae sp.	-	+
Epilobium angustifolium L. ssp. *angustifolium* L.	+	+
Fragaria virginiana Duchesne ssp. *glauca* (S.Wats.) Staudt.	+	+
Galium triflorum Michx.	-	+
Gentianella amarella (L.) Borner ssp. *acuta* (Michx.) Gillett	-	+
Hieracium umbellatum L.	-	+
Lathyrus ochroleucus Hook.	-	+
Lathyrus venosus Muhl.	-	+
Mertensia paniculata (Ait.) G. Don var. *paniculata*	-	+
Moehringia lateriflora (L.) Fenzl.	-	+
Petasites palmatus (Ait.) A. Gray	+	+
Petasites vitifolius Greene	-	+
Potentilla norvegica L.	-	+
Rhinanthus minor L.	-	+
Rubus pubescens Raf.	+	+
Solidago canadensis L.	-	+
Vicia americana Muhl.	+	+
Viola adunca J.E. Smith	-	+

10 and 20 cm LFH mineral soil mix data were pooled for a total of 42 quadrats (including those that were not soil sampled) for each patch type.

Table 3.10. Presence (+) and absence (-) of plant species on bare and vegetated patches on LFH mineral soil mix at W1 dump eight years after reclamation (continued).

Species	Bare	Vegetated
Native pteridophytes		
Equisetum arvense L.	+	+
Native mosses		
Moss sp.	+	+
Native shrubs		
Arctostaphylos uva-ursi (L.) Spreng.	+	+
Rosa acicularis Lindl.	+	+
Rubus idaeus L.	+	+
Salix sp.	-	+
Native trees		
Populus tremuloides Michx.	-	+
Non-native grasses		
Agropyron repens (L.) Beauv.	+	+
Poa pratensis L.	+	-
Non-native forbs		
Cirsium arvense (L.) Scop.	-	+
Crepis tectorum L.	-	+
Melilotus alba Desr.	-	+
Melilotus sp.	-	+
Sonchus arvensis L.	+	+
Taraxacum officinale Weber	+	+
Total	20	46

10 and 20 cm LFH mineral soil mix data were pooled for a total of 42 quadrats (including those that were not soil sampled) for each patch type.

Table 3.11. Presence (+) and absence (-) of plant species on bare and vegetated patches on LFH mineral soil mix at SE dump four years after reclamation.

Species	Bare	Vegetated
Native grasses		
Agroelymus hirtiflorus (A.S. Hitchc.) Bowden	+	+
Bromus ciliatus L.	+	-
Agropyron trachycaulum (Link) Malte		
Agrostis scabra Willd.	+	+
Elymus innovatus Beal	-	+
Hordeum jubatum L.	+	+
Poa palustris L.	+	+
Native sedges		
Carex aenea Fern.	-	+
Carex aurea Nutt.	-	+
Carex sp.	+	+
Native forbs		
Achillea millefolium L.	+	+
Aster ciliolatus Lindl.	+	+
*Aster*aceae sp. 1	+	+
*Aster*aceae sp. 2	+	-
Epilobium angustifolium L. ssp. *angustifolium* L.	+	+
Epilobium ciliatum Raf.	+	-
Fragaria virginiana Duchesne ssp. *glauca* (S.Wats.) Staudt.	+	+
Lathyrus venosus Muhl.	+	-
Mertensia paniculata (Ait.) G. Don var. *paniculata*	+	+
Potentilla norvegica L.	+	-
Rubus pubescens Raf.	-	+
Vicia americana Muhl.	+	+
Native mosses		
Moss sp.	+	+
Native shrubs		
Rubus idaeus L.	+	+
Non-native grasses		
Agropyron repens (L.) Beauv.	+	+
Poa pratensis L.	-	+
Non-native forbs		
Chenopodium album L.	+	+
Sonchus arvensis L.	+	+
Taraxacum officinale Weber	+	+
Total	23	24

There were 7 pairs of quadrats within three replicates of the cover soil treatment.

Table 3.12. Presence (+) and absence (-) of plant species on bare and vegetated patches on LFH mineral soil mix at MLSB thirteen years after reclamation.

	Cell 16		Cell 18	
Species	Bare	Vegetated	Bare	Vegetated
Native grasses				
Agroelymus hirtiflorus (A.S. Hitchc.) Bowden	-	+	+	-
Agropyron trachycaulum (Link) Malte	+	+	-	+
Calamagrostis canadensis (Michx.) Beauv.	-	+	-	-
Elymus innovatus Beal	+	+	-	+
Gramineae spp.	-	-	-	+
Poa palustris L.	-	-	+	+
Native sedges				
Carex aenea Fern.	-	+	-	-
Carex sp.	-	+	+	+
Native forbs				
Aster ciliolatus Lindl.	+	+	+	+
Epilobium angustifolium L. ssp. *angustifolium* L.	-	+	+	+
Fragaria virginiana Duchesne ssp. *glauca* (S.Wats.) Staudt.	+	+	+	+
Native pteridophytes				
Equisetum arvense L.	-	-	+	-
Native mosses				
Moss	-	+	+	+
Native shrubs				
Amelanchier alnifolia Nutt.	-	-	-	+
Rosa acicularis Lindl.	-	+	-	+
Rubus idaeus L.	-	+	-	+
Salix sp.	-	-	-	+
Symphoricarpos albus (L.) Blake	-	+	-	-
Non-native grasses				
Agropyron repens (L.) Beauv.	+	-	+	+
Non-native forbs				
Lotus corniculatus L.	+	+	-	-
Medicago sativa L.	-	-	-	+
Melilotus alba Desr.	-	+	-	-
Melilotus officinalis (L.) Lam.	-	+	-	-
Taraxacum officinale Weber	+	+	+	+
Total	7	17	10	16

There were 4 pairs of quadrats at Cell 16 within one cover soil replicate and there were 6 pairs of quadrats at Cell 18 within three cover soil replicates.

Table 3.13. Cover and proportion of cover of plants groups at bare and vegetated patches on LFH mineral soil mix at W1 dump eight years after reclamation.

	Bare			Vegetated		
	Mean	Median	Range	Mean	Median	Range
Cover (%)						
Total	7.6	6.0	1.0 - 29.0	73.1	73.5	35.0 - 127.0
Grass	0.1	0.0	0.0 - 3.0	2.7	1.0	0.0 - 23.0
Sedge	0.1	0.0	0.0 - 1.0	1.6	0.0	0.0 - 20.0
Forb	5.9	4.5	1.0 - 25.0	46.2	46.5	12.0 - 99.0
Pteridophyte	0.7	0.0	0.0 - 3.0	2.9	2.0	0.0 - 17.0
Moss	0.4	0.0	0.0 - 4.0	5.3	2.5	0.0 - 25.0
Shrub	0.4	0.0	0.0 - 11.0	14.3	11.5	0.0 - 50.0
Tree	0.0	0.0	0.0 - 0.0	0.0	0.0	0.0 - 1.0
Native	7.3	6.0	0.0 - 29.0	69.7	68.5	34.0 - 113.0
Non-native	0.3	0.0	0.0 - 4.0	3.4	1.0	0.0 - 20.0
Proportion of cover (%)						
Grass	1.1	0.0	0 - 30.0	3.6	2.0	0.0 - 29.1
Sedge	1.1	0.0	0 - 16.6	2.2	0.0	0.0 - 35.1
Forb	78.6	83.3	24.9 - 100	63.0	64.8	19.0 - 85.5
Pteridophyte	12.4	0.0	0 - 74.8	3.8	2.9	0.0 - 13.4
Moss	4.1	0.0	0 - 57.1	7.5	3.9	0.0 - 39.7
Shrub	2.6	0.0	0 - 37.9	19.9	16.1	0.0 - 58.1
Tree	0.0	0.0	0.0 - 0.0	0.0	0.0	0.0 - 1.3
Native	95.1	100.0	0.0 - 100.0	95.7	97.7	77.8 - 100
Non-native	4.9	0.0	0.0 - 100.	4.3	2.3	0.0 - 22.2

10 and 20 cm LFH mineral soil mix data were pooled for a total of 42 quadrats (including those that were not soil sampled) for each patch type.

Table 3.14. Cover and proportion of cover of plants groups at bare and vegetated patches on LFH mineral soil mix at SE dump four years after reclamation.

	Bare			Vegetated		
	Mean	Median	Range	Mean	Median	Range
Cover (%)						
Total	20.9	15.0	12.0 - 40.0	74.0	76.0	48.0 - 98.0
Grass	2.7	2.0	0.0 - 8.0	10.9	8.0	5.0 - 22.0
Sedge	0.3	0.0	0.0 - 2.0	1.6	1.0	0.0 - 4.0
Forb	12.9	8.0	2.0 - 33.0	38.3	35.0	17.0 - 67.0
Pteridophyte	0.0	0.0	0.0 - 0.0	0.0	0.0	0.0 - 0.0
Moss	3.0	0.0	0.0 - 12.0	1.0	0.0	0.0 - 3.0
Shrub	2.0	0.0	0.0 - 8.0	22.3	24.0	4.0 - 42.0
Tree	0.0	0.0	0.0 - 0.0	0.0	0.0	0.0 - 0.0
Native	16.3	12.0	9.0 - 29.0	67.6	73.0	43.0 - 87.0
Non-native	4.6	3.0	0.0 - 11.0	6.4	5.0	1.0 - 12.0
Proportion of cover (%)						
Grass	17.2	7.1	0.1 - 66.4	16.0	11.3	6.6 - 37.5
Sedge	1.9	0.0	0.0 - 13.3	2.7	1.4	0.0 - 8.3
Forb	53.1	53.4	16.9 - 82.5	50.5	56.6	21.4 - 79.8
Pteridophyte	0.0	0.0	0.0 - 0.0	0.0	0.0	0.0 - 0.0
Moss	12.2	0.1	0.0 - 46.1	1.1	0.0	0.0 - 3.6
Shrub	15.6	0.0	0.0 - 66.4	29.7	24.5	4.8 - 53.5
Tree	0.0	0.0	0.0 - 0.0	0.0	0.0	0.0 - 0.0
Native	80.6	77.8	72.5 - 99.8	90.9	89.6	78.9 - 98.8
Non-native	19.4	0.2	0.2 - 27.5	9.1	10.4	1.2 - 21.1

There were 7 pairs of quadrats within three replicates of the cover soil treatment.

Table 3.15. Cover and proportion of total cover of plants groups at bare and vegetated patches on LFH mineral soil mix at Cell 18 thirteen years after reclamation.

	Bare			Vegetated		
	Mean	Median	Range	Mean	Median	Range
Cover (%)						
Total	9.7	8.0	3.0 - 22.0	75.2	78.0	48.0 - 96.0
Grass	0.3	0.0	0.0 - 1.0	2.0	0.5	0.0 - 6.0
Sedge	0.5	0.0	0.0 - 2.0	9.0	3.0	0.0 - 40.0
Forb	8.3	7.0	2.0 - 22.0	33.2	39.0	16.0 - 47.0
Pteridophyte	0.2	0.0	0.0 - 1.0	0.0	0.0	0.0 - 0.0
Moss	0.3	0.0	0.0 - 2.0	0.7	0.0	0.0 - 3.0
Shrub	0.0	0.0	0.0 - 0.0	30.3	36.5	3.0 - 47.0
Tree	0.0	0.0	0.0 - 0.0	0.0	0.0	0.0 - 0.0
Native	9.5	8.0	3.0 - 22.0	73.5	75.5	48.0 - 96.0
Non-native	0.2	0.0	0.0 - 1.0	1.7	0.0	0.0 - 5.0
Proportion of cover (%)						
Grass	4.8	0.1	0.0 - 20.0	2.6	1.1	0.0 - 6.9
Sedge	5.2	0.0	0.0 - 16.7	10.2	4.3	0.0 - 41.7
Forb	81.0	87.4	40.0 - 100.0	48.3	48.9	16.7 - 85.4
Pteridophyte	2.4	0.0	0.0 - 14.3	0.0	0.0	0.0 - 0.0
Moss	6.7	0.0	0.0 - 40.0	1.2	0.0	0.0 - 6.2
Shrub	0.0	0.0	0.0 - 0.0	37.6	40.5	6.2 - 58.3
Tree	0.0	0.0	0.0 - 0.0	0.0	0.0	0.0 - 0.0
Native	98.6	100.0	91.7 - 100.0	98.1	100.0	94.0 - 100.0
Non-native	1.4	0.0	0.0 - 8.3	1.9	0.0	0.0 - 6.0

There were 4 pairs of quadrats at Cell 16 within one cover soil replicate and there were 6 pairs of quadrats at Cell 18 within three cover soil replicates.

Table 3.16. Cover and proportion of total cover of plants groups at bare and vegetated patches on LFH mineral soil mix at Cell 16 thirteen years after reclamation.

	Bare			Vegetated		
	Mean	Median	Range	Mean	Median	Range
Cover (%)						
Total	11.0	10.0	4.0 - 20.0	47.5	47.0	46.0 - 50.0
Grass	0.3	0.0	0.0 - 1.0	5.8	5.5	0.0 - 12.0
Sedge	0.0	0.0	0.0 - 0.0	1.5	1.5	0.0 - 3.0
Forb	10.8	10.0	4.0 - 19.0	28.3	27.5	19.0 - 39.0
Pteridophyte	0.0	0.0	0.0 - 0.0	0.0	0.0	0.0 - 0.0
Moss	0.0	0.0	0.0 - 0.0	0.3	0.0	0.0 - 1.0
Shrub	0.0	0.0	0.0 - 0.0	11.8	12.0	4.0 - 19.0
Tree	0.0	0.0	0.0 - 0.0	0.0	0.0	0.0 - 0.0
Native	9.5	7.0	4.0 - 20.0	43.8	46.0	36.0 - 47.0
Non-native	1.5	0.5	0.0 - 5.0	3.8	2.0	0.0 - 11.0
Proportion of cover (%)						
Grass	1.3	0.0	0.0 - 5.0	12.1	11.4	0.0 - 25.5
Sedge	0.0	0.0	0.0 - 0.0	3.2	3.2	0.0 - 6.5
Forb	98.7	100.0	95.0 - 100.0	59.1	58.5	41.3 - 78.0
Pteridophyte	0.0	0.0	0.0 - 0.0	0.0	0.0	0.0 - 0.0
Moss	0.0	0.0	0.0 - 0.0	0.5	0.0	0.0 - 2.0
Shrub	0.0	0.0	0.0 - 0.0	25.1	25.5	8.0 - 41.3
Tree	0.0	0.0	0.0 - 0.0	0.0	0.0	0.0 - 0.0
Native	83.8	95.4	44.4 - 100.0	92.2	96.0	76.6 - 100.0
Non-native	16.2	4.6	0.0 - 55.6	7.8	4.0	0.0 - 23.4

There were 4 pairs of quadrats at Cell 16 within one cover soil replicate and there were 6 pairs of quadrats at Cell 18 within three cover soil replicates.

Table 3.17. Presence (+) and absence (-) of plant species on bare and vegetated patches on peat mineral soil mix at W1 dump eight years after reclamation.

Species	Bare	Vegetated
Native grasses		
Agroelymus hirtiflorus (A.S. Hitchc.) Bowden	-	+
Agrostis scabra Willd.	-	+
Agropyron trachycaulum (Link) Malte	+	+
Bromus ciliatus L.	-	+
Calamagrostis canadensis (Michx.) Beauv.	-	+
Hordeum jubatum L.	-	+
Poa palustris L.	-	+
Native sedges		
Carex aenea Fern.	-	+
Carex aquatilis Wahlenb.	+	+
Carex aurea Nutt.	-	+
Carex chordorrhiza L.f.	+	+
Carex disperma Dewey	-	+
Carex sp.	+	+.
Native forbs		
Achillea millefolium L.	+	+
Achillea sibirica Ledeb.	-	+
Aster ciliolatus Lindl.	+	+
Epilobium angustifolium L. ssp. *angustifolium* L.	+	+
Epilobium ciliatum Raf.	-	+
Fragaria virginiana Duchesne ssp. *glauca* (S.Wats.) Staudt.	+	+
Gentianella amarella (L.) Borner ssp. *acuta* (Michx.) Gillett	-	+
Hieracium umbellatum L.	+	+
Lathyrus venosus Muhl.	-	+
Mertensia paniculata (Ait.) G. Don var. *paniculata*	-	+
Moehringia lateriflora (L.) Fenzl.	-	+
Petasites palmatus (Ait.) A. Gray	+	+
Petasites vitifolius Greene	-	+
Potentilla norvegica L.	-	+
Rubus pubescens Raf.	-	+
Solidago canadensis L.	-	+
Vicia americana Muhl.	+	+
Native pteridophytes		
Equisetum arvense L.	+	+
Equisetum pratense Ehrh.	+	+
Equisetum sylvaticum L.	+	+

10 and 20 cm LFH mineral soil mix data were pooled for a total of 42 quadrats (including those not soil sampled) for each patch type.

Table 3.17. Presence (+) and absence (-) of plant species on bare and vegetated patches on peat mineral soil mix at W1 dump eight years after reclamation (continued).

Species	Bare	Vegetated
Native mosses		
Moss sp.	+	+
Native shrubs		
Arctostaphylos uva-ursi (L.) Spreng.	+	+
Ribes oxyacanthoides L.	-	+
Rosa acicularis Lindl.	-	+
Rubus idaeus L.	+	+
Salix sp.	+	+
Native trees		
Populus tremuloides Michx.	-	+
Non-native grasses		
Agropyron repens (L.) Beauv.	-	+
Poa pratensis L.	-	+
Non-native forbs		
Melilotus alba Desr.	+	+
Melilotus sp.	+	+
Sonchus arvensis L.	+	+
Taraxacum officinale Weber	+	+
Total	22	46

10 and 20 cm LFH mineral soil mix data were pooled for a total of 42 quadrats (including those that were not soil sampled) for each patch type.

Table 3.18. Presence (+) and absence (-) of plant species on bare and vegetated patches on peat mineral soil mix at SE dump four years after reclamation.

Species	Bare	Vegetated
Native grasses		
Agroelymus hirtiflorus (A.S. Hitchc.) Bowden	+	+
Agropyron trachycaulum (Link) Malte	+	+
Bromus ciliatus L.	-	+
Calamagrostis canadensis (Michx.) Beauv.	+	-
Gramineae sp.	+	-
Hordeum jubatum L.	+	+
Poa palustris L.	+	+
Native sedges		
Carex aenea Fern.	-	+
Carex sp.	+	+
Native forbs		
Achillea millefolium L.	+	+
Aster ciliolatus Lindl.	+	+
Epilobium angustifolium L. ssp. *angustifolium* L.	+	+
Epilobium ciliatum Raf.	+	+
Erigeron canadensis L.	+	-
Fragaria virginiana Duchesne ssp. *glauca* (S.Wats.) Staudt.	+	+
Geranium bicknellii Britt.	-	+
Mertensia paniculata (Ait.) G. Don var. *paniculata*	-	+
Potentilla norvegica L.	+	+
Urtica dioica L.	+	-
Vicia americana Muhl.	-	+
Native pteridophytes		
Equisetum arvense L.	+	+
Native mosses		
Moss sp.	+	+
Native shrubs		
Rubus idaeus L.	+	+
Salix sp.	-	+
Non-native grasses		
Agropyron repens (L.) Beauv.	+	-
Poa pratensis L.	+	+
Non-native forbs		
Chenopodium album L.	+	-
Crepis tectorum L.	-	+

There were 10 pairs of quadrats within three replicates of the cover soil treatment.

Table 3.18. Presence (+) and absence (-) of plant species on bare and vegetated patches on peat mineral soil mix at SE dump four years after reclamation (continued).

Species	Bare	Vegetated
Sonchus arvensis L.	+	+
Taraxacum officinale Weber	+	+
Total	23	24

There were 10 pairs of quadrats within three replicates of the cover soil treatment.

Table 3.19. Presence (+) and absence (-) of plant species on bare and vegetated patches on peat mineral soil mix at MLSB thirteen years after reclamation.

	Cell 16		Cell 18	
Species	Bare	Vegetated	Bare	Vegetated
Native grasses				
Agroelymus hirtiflorus (A.S. Hitchc.) Bowden	-	-	+	+
Agropyron trachycaulum (Link) Malte	-	-	-	+
Calamagrostis canadensis (Michx.) Beauv.	-	-	-	+
Poa palustris L.	-	-	+	+
Native sedges				
Carex sp.	-	-	-	+
Native forbs				
Achillea millefolium L.	-	-	-	+
Aster ciliolatus Lindl.	+	+	-	+
Epilobium angustifolium L. ssp. *angustifolium* L.	-	+	-	+
Fragaria virginiana Duchesne ssp. *glauca* (S.Wats.) Staudt.	-	+	+	+
Solidago canadensis L.	-	+	-	-
Native mosses				
Moss sp.	+	+	+	+
Native shrubs				
Rubus idaeus L.	-	+	+	+
Non-native grasses				
Agropyron repens (L.) Beauv.	+	+	-	-
Non-native forbs				
Lotus corniculatus L.	+	+	-	+
Medicago sativa L.	-	-	-	+
Melilotus sp.	-	-	-	+
Sonchus arvensis L.	-	+	-	-
Taraxacum officinale Weber	+	+	+	+
Total	5	10	6	15

There were 2 pairs of quadrats at Cell 16 within one cover soil replicate and there were 6 pairs of quadrats at Cell 18 within two cover soil replicates.

Table 3.20. Cover and proportion of cover of plants groups at bare and vegetated patches on peat mineral soil mix at W1 dump eight years after reclamation.

	Bare			Vegetated		
	Mean	Median	Range	Mean	Median	Range
Cover (%)						
Total	5.9	4.0	0.0 - 17.0	64.2	61.5	19.0 - 121.0
Grass	0.0	0.0	0.0 - 1.0	1.0	0.0	0.0 - 13.0
Sedge	0.5	0.0	0.0 - 5.0	4.9	2.0	0.0 - 47.0
Forb	3.0	2.0	0.0 - 11.0	25.0	20.5	8.0 - 61.0
Pteridophyte	1.9	1.5	0.0 - 9.0	3.0	3.0	0.0 - 10.0
Moss	0.0	0.0	0.0 - 0.0	3.0	0.0	0.0 - 45.0
Shrub	0.6	0.0	0.0 - 15.0	26.7	23.0	0.0 - 85.0
Tree	0.0	0.0	0.0 - 0.0	0.6	0.0	0.0 - 22.0
Native	4.7	3.5	0.0 - 17.0	57.7	55.5	13.0 - 112.0
Non-native	1.2	1.0	0.0 - 5.0	6.5	6.0	0.0 - 17.0
Proportion of cover (%)						
Grass	0.5	0.0	0.0 - 19.9	1.5	0.0	0.0 - 19.4
Sedge	8.8	0.0	0.0 - 71.0	7.0	3.7	0.0 - 49.0
Forb	53.0	50.0	0.0 - 100.0	43.4	40.0	7.4 - 92.0
Pteridophyte	33.3	31.5	0.0 - 100.0	5.6	5.0	0.0 - 17.0
Moss	0.0	0.0	0.0 - 0.0.2	4.5	0.0	0.0 - 47.9
Shrub	4.4	0.0	0.0 - 88.1	36.9	40.2	0.0 - 80.8
Tree	0.0	0.0	0.0 - 0.0	1.1	0.0	0.0 - 37.3
Native	76.0	79.6	33.3 - 100.0	88.6	90.3	68.5 - 100.0
Non-native	24.0	20.4	0.0 - 66.7	11.4	9.7	0.0 - 31.5

10 and 20 cm LFH mineral soil mix data were pooled for a total of 42 quadrats (including those not soil sampled) for each patch type.

Table 3.21. Cover and proportion of total cover of plant groups at bare and vegetated patches on peat mineral soil mix at SE dump four years after reclamation.

	Bare			Vegetated		
	Mean	Median	Range	Mean	Median	Range
Cover (%)						
Total	14.7	13.5	4.0 - 29.0	71.5	72.0	53.0 - 87.0
Grass	0.6	0.0	0.0 - 5.0	5.3	5.0	0.0 - 17.0
Sedge	0.2	0.0	0.0 - 2.0	1.3	0.0	0.0 - 5.0
Forb	9.0	8.5	3.0 - 17.0	46.2	42.0	26.0 - 81.0
Pteridophyte	0.3	0.0	0.0 - 1.0	0.3	0.0	0.0 - 1.0
Moss	4.5	1.0	0.0 - 22.0	0.5	0.0	0.0 - 2.0
Shrub	0.1	0.0	0.0 - 1.0	17.9	15.5	0.0 - 50.0
Tree	0.0	0.0	0.0 - 0.0	0.0	0.0	0.0 - 0.0
Native	8.9	6.0	0.1 - 26.0	61.9	61.0	46.0 - 81.0
Non-native	5.8	3.5	2.0 - 16.0	9.6	8.5	3.0 - 17.0
Proportion of cover (%)						
Grass	4.7	0.1	0.0 - 24.9	7.2	6.9	0.0 - 22.7
Sedge	0.7	0.0	0.0 - 6.9	2.0	0.0	0.0 - 7.6
Forb	71.5	81.3	17.3 - 99.9	65.9	68.3	30.2 - 95.3
Pteridophyte	3.0	0.0	0.0 - 16.6	0.4	0.0	0.0 - 1.5
Moss	19.8	4.2	0.0 - 75.8	0.7	0.0	0.0 - 3.0
Shrub	0.4	0.0	0.0 - 4.0	23.9	21.2	0.0 - 58.1
Tree	0.0	0.0	0.0 - 0.0	0.0	0.0	0.0 - 0.0
Native	50.2	50.1	0.5 - 89.7	86.5	85.7	76.7 - 95.4
Non-native	49.8	49.9	10.3 - 99.5	13.5	14.3	4.6 - 23.3

There were 10 pairs of quadrats within three replicates of the cover soil treatment.

Table 3.22. Cover and proportion of total cover of plants groups at bare and vegetated patches on peat mineral soil mix at Cell 18 thirteen years after reclamation.

	Bare			Vegetated		
	Mean	Median	Range	Mean	Median	Range
Cover (%)						
Total	8.3	6.5	0.0 - 20.0	41.5	33.5	20.0 - 83.0
Grass	0.8	0.5	0.0 - 3.0	2.5	2.5	0.0 - 5.0
Sedge	0.0	0.0	0.0 - 0.0	0.0	0.0	0.0 - 0.0
Forb	5.2	5.0	0.0 - 13.0	31.7	31.0	14.0 - 50.0
Pteridophyte	0.0	0.0	0.0 - 0.0	0.0	0.0	0.0 - 0.0
Moss	2.2	1.5	0.0 - 5.0	2.7	1.5	0.0 - 9.0
Shrub	0.2	0.0	0.0 - 1.0	4.7	0.0	0.0 - 28.0
Tree	0.0	0.0	0.0 - 0.0	0.0	0.0	0.0 - 0.0
Native	5.3	3.0	0.0 - 20.0	30.8	19.0	0.0 - 82.0
Non-native	3.0	2.0	0.0 - 8.0	10.7	10.0	0.0 - 29.0
Proportion of cover (%)						
Grass	13.9	5.0	0.0 - 50.0	7.7	8.4	0.0 - 15.0
Sedge	0.0	0.0	0.0 - 0.0	0.0	0.0	0.0 - 0.0
Forb	62.4	65.0	0.0 - 99.8	80.8	82.4	60.3 - 100.0
Pteridophyte	0.0	0.0	0.0 - 0.0	0.0	0.0	0.0 - 0.0
Moss	22.7	25.0	0.0 - 50.0	5.9	2.4	0.0 - 15.3
Shrub	1.0	0.0	0.0 - 5.0	5.6	0.0	0.0 - 33.7
Tree	0.0	0.0	0.0 - 0.0	0.0	0.0	0.0 - 0.0
Native	50.6	38.5	0.2 - 100.0	59.5	64.2	0.0 - 100.0
Non-native	49.4	61.5	0.0 - 99.8	40.5	35.8	0.0 - 100.0

There were 2 pairs of quadrats at Cell 16 within one cover soil replicate and there were 6 pairs of quadrats at Cell 18 within two cover soil replicates.

Table 3.23. Cover and proportion of total cover of plants groups at bare and vegetated patches on peat mineral soil mix at Cell 16 thirteen years after reclamation.

	Bare			Vegetated		
	Mean	Median	Range	Mean	Median	Range
Cover (%)						
Total	11.0	11.0	2.0 - 20.0	48.0	48.0	40.0 - 56.0
Grass	0.0	0.0	0.0 - 0.0	1.0	1.0	0.0 - 2.0
Sedge	0.0	0.0	0.0 - 0.0	0.0	0.0	0.0 - 0.0
Forb	7.0	7.0	1.0 - 13.0	34.5	34.5	33.0 - 36.0
Pteridophyte	0.0	0.0	0.0 - 0.0	0.0	0.0	0.0 - 0.0
Moss	4.0	4.0	1.0 - 7.0	10.0	10.0	5.0 - 15.0
Shrub	0.0	0.0	0.0 - 0.0	2.5	2.5	0.0 - 5.0
Tree	0.0	0.0	0.0 - 0.0	0.0	0.0	0.0 - 0.0
Native	7.0	7.0	1.0 - 13.0	36.0	36.0	26.0 - 46.0
Non-native	4.0	4.0	1.0 - 7.0	12.0	12.0	10.0 - 14.0
Proportion of cover (%)						
Grass	0.2	0.2	0.0 - 0.5	2.5	2.5	0.0 - 5.0
Sedge	0.0	0.0	0.0 - 0.0	0.0	0.0	0.0 - 0.0
Forb	57.4	57.4	49.8 - 65.0	73.4	73.4	64.3 - 82.5
Pteridophyte	0.0	0.0	0.0 - 0.0	0.0	0.0	0.0 - 0.0
Moss	42.4	42.4	35.0 - 49.8	19.6	19.6	12.5 - 26.8
Shrub	0.0	0.0	0.0 - 0.0	4.5	4.5	0.0 - 8.9
Tree	0.0	0.0	0.0 - 0.0	0.0	0.0	0.0 - 0.0
Native	57.4	57.7	49.8 - 65.0	73.6	73.6	65.0 - 82.4
Non-native	42.6	42.6	35.0 - 50.2	26.4	26.4	17.9 - 32.0

There were 2 pairs of quadrats at Cell 16 within one cover soil replicate and there were 6 pairs of quadrats at Cell 18 within two cover soil replicates.

Table 3.24. Upper layer soil physical properties of bare and vegetated patches on 10 cm LFH mineral soil mix at W1 dump eight years after reclamation.

	Bare			Vegetated		
	Mean	Median	Range	Mean	Median	Range
Cover soil depth 1 (cm)	0.7[b]	0.0	0.0 - 7.0	13.4[a]	12.0	0.0 - 29.0
Cover soil depth 2 (cm)	0.9[b]	0.0	0.0 - 8.0	13.4[a]	12.0	4.5 - 29.0
Sand (%)	35.2	33.0	29.0 - 42.6	34.3	34.0	30.0 - 41.4
Silt (%)	34.6[b]	33.4	27.8 - 42.0	38.9[a]	38.4	36.0 - 44.0
Clay (%)	30.2[a]	31.6	19.6 - 36.6	26.8[b]	27.2	22.2 - 32.0
Texture	Clay loam	Clay loam	-	Loam	Loam	-
Saturation (%)	26.59[b]	26.56	19.49 - 31.36	44.79[a]	43.98	32.70 - 64.26
Field capacity (%)	22.98[b]	23.42	18.10 - 25.44	36.20[a]	33.46	26.53 - 54.45
Wilting point (%)	8.45[b]	8.72	3.71 - 10.10	15.39[a]	12.79	8.17 - 29.92
Water holding capacity (%)	14.53[b]	14.39	12.59 - 16.64	20.80[a]	20.85	16.25 - 24.53
Bulk density (g / cm^3)	1.35[a]	1.36	1.06 - 1.54	0.94[b]	0.88	0.68 - 1.34
Volumetric water content (%)	15.95	15.69	9.17 - 21.79	15.98	16.22	11.48 - 20.66

Saturation, field capacity and wilting point were measured as water retention (gravimetric) at 0.1, 0.3 and 15 bar, respectively.
There were 17 pairs of quadrats within 3 cover soil replicates, except for bulk density and volumetric water content (quadrats were removed from analysis).
Lower case letters indicate significant differences between bare and vegetated quadrats at $p < 0.05$.

Table 3.25. Upper layer soil physical properties of bare and vegetated patches on 20 cm LFH mineral soil mix at W1 dump eight years after reclamation.

	Bare			Vegetated		
	Mean	Median	Range	Mean	Median	Range
Cover soil depth 1 (cm)	1.7^{b}	0.0	0.0 - 7.0	11.7^{a}	12.0	0.0 - 23.0
Cover soil depth 2 (cm)	6.1^{b}	0.0	0.0 - 23.0	12.5^{a}	13.0	0.0 - 23.0
Sand (%)	35.5	35.0	26.4 - 45.0	33.9	34.0	28.0 - 39.4
Silt (%)	33.6^{b}	33.8	16.0 - 49.6	39.6^{a}	39.6	32.8 - 46.0
Clay (%)	30.9^{a}	30.0	19.0 - 44.4	26.4^{b}	25.6	18.3 - 34.6
Texture	Clay loam	Clay loam	-	Loam	Loam	-
Saturation (%)	31.62^{b}	31.46	25.34 - 42.75	46.96^{a}	45.62	29.46 - 71.05
Field capacity (%)	25.19^{b}	23.94	20.60 - 33.86	35.63^{a}	33.96	21.07 - 53.75
Wilting point (%)	10.16^{b}	10.43	4.59 - 13.60	16.49^{a}	15.29	8.84 - 30.04
Water holding capacity (%)	15.03^{b}	13.97	10.78 - 22.02	19.14^{a}	19.33	11.68 - 26.77
Bulk density (g / cm^3)	1.26^{a}	1.29	0.74 - 1.40	0.96^{b}	0.99	0.40 - 1.45
Volumetric water content (%)	14.31	14.36	9.80 - 21.66	14.90	14.81	11.33 - 18.70

Saturation, field capacity and wilting point were measured as water retention (gravimetric) at 0.1, 0.3 and 15 bar, respectively.
There were 15 pairs of quadrats within 3 cover soil replicates, except for bulk density and volumetric water content (quadrats were removed from analysis).
Lower case letters indicate significant differences between bare and vegetated quadrats at $p < 0.05$.

Table 3.26. Upper layer soil physical properties of bare and vegetated patches on 10 cm peat mineral soil mix at W1 dump eight years after reclamation.

	Bare			Vegetated		
	Mean	Median	Range	Mean	Median	Range
Cover soil depth 1 (cm)	3.4^{b}	0.0	0.0 - 13.0	14.4^{a}	15.5	7.5 - 20.0
Cover soil depth 2 (cm)	4.4^{b}	0.0	0.0 - 13.0	14.4^{a}	15.5	7.5 - 20.0
Sand (%)	33.7	35.0	27.4 - 40.4	33.4	32.4	27.7 - 41.7
Silt (%)	34.7^{b}	33.4	28.4 - 43.4	37.4^{a}	37.8	32.3 - 42.3
Clay (%)	31.5^{a}	31.6	18.6 - 43.6	29.2^{b}	29.3	23.3 - 35.2
Texture	Clay loam	Clay loam	-	Clay loam	Clay loam	-
Saturation (%)	33.17^{b}	29.44	25.16 - 49.44	75.47^{a}	76.41	41.70 - 121.60
Field capacity (%)	27.07^{b}	23.96	19.91 - 38.61	58.92^{a}	60.30	31.55 - 97.35
Wilting point (%)	10.72^{b}	10.06	5.05 - 16.29	27.76^{a}	24.96	12.60 - 58.39
Water holding capacity (%)	16.35^{b}	14.32	11.37 - 25.18	31.16^{a}	31.90	16.72 - 43.83
Bulk density (g / cm^3)	1.27^{a}	1.35	0.72 - 1.49	0.72^{b}	0.74	0.23 - 1.21
Volumetric water content (%)	17.32	17.43	13.09 - 22.90	16.86	15.51	13.04 - 33.69

Saturation, field capacity and wilting point were measured as water retention (gravimetric) at 0.1, 0.3 and 15 bar, respectively.
There were 15 pairs of quadrats within 3 cover soil replicates, except for bulk density and volumetric water content (quadrats were removed from analysis).
Lower case letters indicate significant differences between bare and vegetated quadrats at $p < 0.05$.

Table 3.27. Upper layer soil physical properties of bare and vegetated patches on 20 cm peat mineral soil mix at W1 dump eight years after reclamation.

	Bare			Vegetated		
	Mean	Median	Range	Mean	Median	Range
Cover soil depth 1 (cm)	7.9^{b}	8.8	0.0 - 18.0	17.9^{a}	18.0	7.0 - 30.0
Cover soil depth 2 (cm)	8.3^{b}	10.0	0.0 - 18.0	17.9^{a}	18.0	7.0 - 30.0
Sand (%)	33.9	33.4	25.4 - 45.0	35.1	34.4	29.0 - 42.0
Silt (%)	32.6^{b}	35.0	17.4 - 40.6	37.1^{a}	37.4	30.4 - 42.3
Clay (%)	33.5^{a}	32.0	26.0 - 46.6	27.8^{b}	28.2	20.0 - 34.6
Texture	Clay loam	Clay loam	-	Clay loam	Clay loam	-
Saturation (%)	39.21^{b}	35.80	26.46 - 56.47	76.91^{a}	70.55	50.00 - 160.10
Field capacity (%)	31.65^{b}	32.00	21.79 - 50.10	59.45^{a}	55.59	38.63 - 128.12
Wilting point (%)	13.03^{b}	12.63	7.95 - 24.29	26.90^{a}	23.71	16.71 - 63.08
Water holding capacity (%)	18.62^{b}	18.40	11.03 - 29.04	32.55^{a}	31.39	21.71 - 65.04
Bulk density (g / cm^3)	1.07^{a}	1.15	0.59 - 1.43	0.64^{b}	0.63	0.39 - 1.22
Volumetric water content (%)	16.11	14.39	12.81 - 23.85	15.04	13.27	10.59 - 21.06

Saturation, field capacity and wilting point were measured as water retention (gravimetric) at 0.1, 0.3 and 15 bar, respectively.
There were 19 pairs of quadrats within 3 cover soil replicates, except for bulk density and volumetric water content (quadrats were removed from analysis).
Lower case letters indicate significant differences between bare and vegetated quadrats at $p < 0.05$.

Table 3.28. Upper layer soil physical properties of bare and vegetated patches on LFH mineral soil mix at SE dump four years after reclamation.

	Bare			Vegetated		
	Mean	Median	Range	Mean	Median	Range
Cover soil depth 1 (cm)	16.9	18.0	3.0 - 27.0	17.0	17.0	12.0 - 22.0
Cover soil depth 2 (cm)	19.2	18.0	9.0 - 27.0	17.0	17.0	12.0 - 22.0
Sand (%)	47.4	47.4	43.3 - 52.0	48.8	49.4	43.3 - 52.8
Silt (%)	38.8	38.2	33.6 - 45.0	39.4	39.0	35.0 - 45.0
Clay (%)	13.8	13.0	11.7 - 18.0	11.8	11.7	10.0 - 13.6
Texture	Loam	Loam	-	Loam	Loam	-
Saturation (%)	50.82	42.85	26.64 - 87.92	62.73	56.09	43.68 - 91.77
Field capacity (%)	38.13	30.82	19.61 - 67.68	46.87	43.67	29.40 - 67.36
Wilting point (%)	17.62	13.52	5.00 - 35.47	23.85	21.12	13.06 - 45.76
Water holding capacity (%)	20.50	19.56	14.61 - 32.21	23.02	22.56	16.34 - 32.79
Bulk density (g / cm^3)	0.63	0.63	0.59 - 0.68	0.63	0.68	0.38 - 0.80
Volumetric water content (%)	18.23	18.23	8.67 - 27.78	13.79	13.15	11.76 - 17.11

Saturation, field capacity and wilting point were measured as water retention (gravimetric) at 0.1, 0.3 and 15 bar, respectively.
There were 7 pairs of quadrats within 3 cover soil replicates, except for bulk density and volumetric water content (quadrats were removed from analysis).
There were no significant differences between bare and vegetated quadrats at $p < 0.05$.
Statistical analysis was not possible for bulk density on LFH mineral soil mix due to low sample size.

Table 3.29. Upper layer soil physical properties of bare and vegetated patches on peat mineral soil mix at SE dump four years after reclamation.

	Bare			Vegetated		
	Mean	Median	Range	Mean	Median	Range
Cover soil depth (cm)	19.4	16.5	12.0 - 30.0	24.9	30.0	10.0 -30.0
Sand (%)	47.6	47.5	40.4 - 52.0	48.6	49.5	44.7 - 52.4
Silt (%)	32.2	32.0	29.6 - 34.0	32.1	31.2	29.0 - 38.7
Clay (%)	20.2	19.8	16.4 - 27.6	19.3	18.7	16.4 - 23.0
Texture	Loam	Loam	-	Loam	Loam	-
Saturation (%)	46.85	44.48	30.85 - 64.63	54.52	56.52	38.87 - 73.36
Field capacity (%)	38.63	38.43	23.30 - 56.32	43.59	44.91	31.49 - 57.24
Wilting point (%)	16.28	15.76	8.63 - 25.95	19.22	18.72	13.33 - 28.63
Water holding capacity (%)	22.36	23.71	14.06 - 30.37	24.37	24.68	15.48 - 31.20
Bulk density (g / cm^3)	1.06	1.05	0.77 - 1.41	0.86	0.93	0.47 - 0.98
Volumetric water content (%)	20.17	20.37	16.59 - 23.31	19.37	20.51	14.32 - 21.55

Saturation, field capacity and wilting point were measured as water retention (gravimetric) at 0.1, 0.3 and 15 bar, respectively.
There were 10 pairs of quadrats within 3 cover soil replicates, except for bulk density and volumetric water content (quadrats were removed from analysis).
There were no significant differences between bare and vegetated quadrats at $p < 0.05$.
Statistical analysis was not possible for bulk density on LFH mineral soil mix due to low sample size.

Table 3.30. Upper layer soil physical properties of bare and vegetated patches on LFH mineral soil mix at Cell 18 (MLSB) thirteen years after reclamation.

	Bare			Vegetated		
	Mean	Median	Range	Mean	Median	Range
Cover soil depth (cm)	17.8	17.75	4.0 - 3.0	17.3	15.5	9.0 - 30.0
Sand (%)	33.4	33.1	28.8 - 37.4	35.4	36.1	30.0 - 38.0
Silt (%)	35.3	38.3	27.6 - 40.2	36.6	35.1	32.4 - 42.6
Clay (%)	31.3	28.7	25.6 - 43.6	28.0	28.5	21.6 - 37.6
Texture	Clay loam	Clay loam	-	Clay loam	Clay loam	-
Saturation (%)	48.51	47.62	39.31 - 56.52	52.18	50.40	45.18 - 65.40
Field capacity (%)	39.16	38.34	33.59 - 44.57	41.45	39.45	36.42 - 51.24
Wilting point (%)	20.13	18.83	16.43 - 26.32	21.51	19.63	17.40 - 29.54
Water holding capacity (%)	19.03	19.51	16.17 - 21.60	19.94	19.64	19.02 - 21.70
Bulk density (g / cm^3)	1.07	1.07	0.76 - 1.37	0.76	0.76	0.62 - 0.89
Volumetric water content (%)	12.69	12.69	9.47 - 15.91	13.58	13.58	9.47 - 17.69

Saturation, field capacity and wilting point were measured as water retention (gravimetric) at 0.1, 0.3 and 15 bar, respectively.
There were 6 pairs of quadrats within 3 cover soil replicates, except for bulk density and volumetric water content (quadrats were removed from analysis).
There were no significant differences between bare and vegetated quadrats at $p < 0.05$.

Table 3.31. Upper layer soil physical properties of bare and vegetated patches on LFH mineral soil mix at Cell 16 (MLSB) thirteen years after reclamation.

	Bare			Vegetated		
	Mean	Median	Range	Mean	Median	Range
Cover soil depth (cm)	7.5	0.0	0.0 - 30.0	13.9	14.0	0.0 - 27.5
Sand (%)	35.7	35.6	30.0 - 41.4	33.9	33.4	32.4 - 36.4
Silt (%)	28.3	27.1	23.6 - 35.2	36.2	37.1	26.6 - 44.0
Clay (%)	36.1	36.0	26.0 - 46.4	29.9	27.5	23.6 - 41.0
Texture	Clay loam	Clay loam	-	Clay loam	Clay loam	-
Saturation (%)	32.25	30.50	29.31 - 38.69	40.30	40.73	29.68 - 50.05
Field capacity (%)	25.97	24.26	22.87 - 32.48	32.35	32.67	25.33 - 38.70
Wilting point (%)	12.41	12.22	11.27 - 13.93	14.26	14.33	12.74 - 15.63
Water holding capacity (%)	13.56	12.04	11.60 - 18.56	18.09	18.35	12.59 - 23.07
Bulk density (g / cm^3)	1.07	1.07	0.81 - 1.34	0.87	0.91	0.60 - 1.08
Volumetric water content (%)	12.81	12.63	10.32 - 15.67	13.26	13.47	10.44 - 15.68

Saturation, field capacity and wilting point were measured as water retention (gravimetric) at 0.1, 0.3 and 15 bar, respectively.
There were 4 pairs of quadrats within 1 cover soil replicate, except for bulk density and volumetric water content (quadrats were removed from analysis).
There were no significant differences between bare and vegetated quadrats at $p < 0.05$.

Table 3.32. Upper layer soil physical properties of bare and vegetated patches on peat mineral soil mix at Cell 18 (MLSB) thirteen years after reclamation.

	Bare			Vegetated		
	Mean	Median	Range	Mean	Median	Range
Cover soil depth (cm)	4.5	3.0	0.0 - 15.0	8.3	8.0	0.0 - 16.0
Sand (%)	30.6	24.7	10.4 - 54.4	30.6	29.1	26.4 - 40.0
Silt (%)	25.5	25.9	18.0 - 33.0	29.2	26.9	22.4 - 37.7
Clay (%)	43.9	43.7	24.0 - 71.6	40.3	39.8	31.7 - 49.6
Texture	Clay	Clay	-	Clay	Clay loam	
Saturation (%)	36.24	34.76	23.06 - 55.51	45.72	40.13	27.59 - 83.19
Field capacity (%)	30.41	29.31	16.16 - 45.19	38.25	33.33	22.05 - 70.30
Wilting point (%)	15.64	15.48	8.14 - 23.91	19.13	17.93	10.57 - 33.70
Water holding capacity (%)	14.77	13.72	8.02 - 21.28	19.12	15.40	11.48 - 36.60
Bulk density (g / cm^3)	1.30	1.42	0.90 - 1.50	1.04	1.10	0.73 - 1.37
Volumetric water content (%)	13.25	14.81	6.08 - 16.84	17.91	17.44	15.98 - 20.40

Saturation, field capacity and wilting point were measured as water retention (gravimetric) at 0.1, 0.3 and 15 bar, respectively.
There were 6 pairs of quadrats within 2 cover soil replicates, except for bulk density and volumetric water content (quadrats were removed from analysis).
There were no significant differences between bare and vegetated quadrats at $p < 0.05$.
Statistical analysis was not possible for upper layer sand content on peat mineral soil mix due to inequality of variance.

Table 3.33. Upper layer soil physical properties of bare and vegetated patches on peat mineral soil mix at Cell 16 (MLSB) thirteen years after reclamation.

	Bare			Vegetated		
	Mean	Median	Range	Mean	Median	Range
Cover soil depth (cm)	9.0	9.0	8.0 - 10.0	11.0	11.0	11.0 - 11.0
Sand (%)	62.2	62.2	60.4 - 64.0	57.6	57.6	54.4 - 60.7
Silt (%)	26.5	26.5	23.6 - 29.3	27.2	27.2	26.6 - 27.7
Clay (%)	11.4	11.4	6.7 - 16.0	15.4	15.4	11.7 - 19.0
Texture	Sandy loam	Sandy loam	-	Sandy loam	Sandy loam	-
Saturation (%)	69.78	69.78	59.39 - 80.17	73.28	73.28	63.21 - 83.35
Field capacity (%)	53.92	53.92	44.21 - 63.63	56.45	56.45	47.65 - 65.25
Wilting point (%)	27.62	27.62	22.93 - 32.31	32.25	32.25	24.51 - 39.98
Water holding capacity (%)	26.30	26.30	21.28 - 31.32	24.20	24.20	23.14 - 25.27
Bulk density (g / cm^3)	0.49	0.49	0.49 - 0.49	0.61	0.61	0.61 - 0.61
Volumetric water content (%)	26.50	26.50	26.50 - 26.50	32.03	32.03	32.03 - 32.03

Saturation, field capacity and wilting point were measured as water retention (gravimetric) at 0.1, 0.3 and 15 bar, respectively.
There were 2 pairs ofquadrats within 1 cover soil replicate, except for bulk density and volumetric water content (quadrats were removed from analysis).
There were no significant differences between bare and vegetated quadrats at $p < 0.05$.
Statistical analysis was not possible for upper layer EC on peat mineral soil mix due to inequality of variance.

Table 3.34. Upper layer soil chemical properties of bare and vegetated patches on LFH mineral soil mix at W1 dump eight years after reclamation.

	Bare						Vegetated					
	10 cm LFH mineral soil mix			20 cm LFH mineral soil mix			10 cm LFH mineral soil mix			20 cm LFH mineral soil mix		
	Mean	Median	Range	Mean	Median	Range	Mean	Median	Range	Mean	Median	Range
OM (%)	2.78^{b}	2.65	2.18 - 4.54	4.18^{b}	2.73	2.00 - 12.10	9.85^{a}	9.12	5.30 - 18.70	11.55^{a}	11.70	1.30 - 21.30
TIC (%)	0.36^{a}	0.41	0.00 - 0.49	0.25^{b}	0.27	0.00 - 0.53	0.13^{b}	0.11	0.06 - 0.22	0.17^{b}	0.19	0.00 - 0.40
TOC (%)	1.39^{b}	1.32	1.09 - 2.27	2.09^{b}	1.37	1.00 - 6.06	4.93^{a}	4.56	2.65 - 9.35	5.77^{a}	5.86	0.65 - 10.60
TC (%)	1.75^{b}	1.70	1.46 - 2.36	2.34^{b}	1.81	1.28 - 6.16	5.05^{a}	4.64	2.75 - 9.55	5.95^{a}	5.96	0.65 - 10.76
TN (%)	0.04^{b}	0.03	0.02 - 0.02	0.07^{b}	0.04	0.02 - 0.27	0.24^{a}	0.18	0.11 - 0.56	0.27^{a}	0.28	0.02 - 0.54
C:N	53.96^{a}	53.00	22.86-87.00	42.77^{a}	39.25	22.33-90.50	22.68^{b}	23.63	17.05-29.19	26.11^{b}	22.95	19.13-59.33
BS (%)	233^{a}	230	84 - 360	160^{a}	160	72 - 270	113^{b}	100	80 - 260	118^{b}	105	83 - 220
Ca (meq / 100g)	20.5	21.7	5.3 - 26.6	18.8	20.0	5.0 - 28.0	24.4	20.8	12.8 - 64.0	24.0	23.8	14.3 - 32.8
Mg (meq / 100g)	3.2^{b}	3.0	2.0 - 5.9	3.5^{b}	3.4	1.8 - 5.6	6.3^{a}	5.5	3.2 - 18.2	5.3^{a}	5.4	2.4 - 8.9
Na (meq / 100g)	0.6	0.2	0.1 - 4.2	0.2	0.2	0.1 - 0.4	0.5	0.2	0.1 - 4.1	0.2	0.2	0.1 - 0.2
K (meq / 100g)	0.2^{b}	0.2	0.1 - 0.2	0.2^{b}	0.2	0.2 - 0.3	0.5^{a}	0.4	0.3 - 1.0	0.5^{a}	0.4	0.2 - 1.0
ESP (%)	5.5	2.0	0.9 - 41.0	1.4	1.0	0.7 - 2.0	1.8	1.0	0.3 - 11.0	0.7	0.5	0.4 - 2.0
TEC (meq / 100g)	24	25	8 - 37	23	24	7 - 32	32	26	16 - 85	30	30	18 - 41
CEC (meq / 100g)	10^{b}	10	9 - 14	15^{b}	15	9 - 32	29^{a}	23	15 - 68	28^{a}	30	11 - 46
pH	7.6	7.9	5.7 - 8.0	7.2	7.8	4.9 - 8.0	7.1	7.2	6.1 - 7.6	7.2	7.0	6.5 - 7.9
EC (dS / m)	1.43	0.66	0.40 - 6.44	1.06	0.80	0.33 - 2.69	1.12	0.90	0.59 - 3.58	0.64	0.59	0.46 - 1.02

OM = organic matter. TIC = total inorganic carbon. TOC = total organic carbon. TC = total carbon. TN = total nitrogen. C:N = carbon nitrogen ratio. BS = base saturation. Ca = exchangeable calcium. Mg = exchangeable magnesium. Na = exchangeable sodium. K = exchangeable potassium. ESP = exchangeable sodium percentage. TEC = total exchange capacity. CEC = cation exchange capacity. EC = electrical conductivity.
There were 17 and 15 pairs of quadrats on 10 cm and 20 cm treatments, respectively, within 3 replicates of each application depth.Lower case letters indicate significant differences between bare and vegetated quadrats ($p < 0.05$).
Statistical analysis was not possible for upper layer EC, exchangeable Na or ESP on LFH mineral soil mix due to inequality of variance.

Table 3.35. Lower layer soil chemical properties of bare and vegetated patches on LFH mineral soil mix at W1 dump eight years after reclamation.

	Bare						Vegetated					
	10 cm LFH mineral soil mix			20 cm LFH mineral soil mix			10 cm LFH mineral soil mix			20 cm LFH mineral soil mix		
	Mean	Median	Range	Mean	Median	Range	Mean	Median	Range	Mean	Median	Range
OM (%)	2.60^{b}	2.53	1.71 - 4.83	2.56^{b}	2.56	1.60 - 3.20	3.42^{a}	2.96	1.97 - 7.10	3.21^{a}	3.10	2.29 - 5.69
TIC (%)	0.39	0.43	0.00 - 0.49	0.37	0.41	0.00 - 0.52	0.32	0.33	0.08 - 0.46	0.32	0.34	0.00 - 0.52
TOC (%)	1.30^{b}	1.27	0.86 - 2.42	1.28^{b}	1.28	0.78 - 1.60	1.71^{a}	1.48	0.98 - 3.55	1.61^{a}	1.55	1.15 - 2.85
TC (%)	1.69^{b}	1.72	1.32 - 2.42	1.65^{b}	1.73	0.99 - 1.95	2.03^{a}	1.90	1.27 - 3.63	1.93^{a}	1.92	1.49 - 2.94
TN (%)	0.03	0.02	0.00 - 0.11	0.03	0.02	0.00 - 0.06	0.04	0.03	0.00 - 0.12	0.04	0.03	0.02 - 0.13
C:N	73.20	77.00	22.00-102.50	64.81	62.00	21.00-97.50	61.67	53.00	30.25-167.00	62.37	63.00	22.62-09.50
BS (%)	255	260	55 - 320	216	230	100 - 270	221	210	99 - 320	212	220	100 - 270
Ca (meq / 100g)	21.7	22.4	5.3 - 25.2	20.8	21.4	8.7 - 25.5	21.9	22.0	15.1 - 26.4	21.2	21.0	13.3 - 25.0
Mg (meq / 100g)	3.1	2.9	1.4 - 5.5	2.9	2.9	2.0 - 4.2	3.4	3.4	2.1 - 4.9	3.0	2.8	2.1 - 4.7
Na (meq / 100g)	0.5	0.2	0.1 - 3.1	0.2	0.2	0.1 - 0.2	0.5	0.2	0.1 - 3.3	0.1	0.1	0.1 - 0.3
K (meq / 100g)	0.2	0.2	0.1 - 0.2	0.2	0.2	0.2 - 0.3	0.2	0.2	0.2 - 0.2	0.2	0.2	0.2 - 0.4
ESP (%)	4.7	2.0	1.0 - 25.0	1.5	1.0	1.0 - 3.0	4.5	2.0	0.9 - 28.0	1.2	1.0	0.7 - 3.0
TEC (meq / 100g)	25	26	7 - 33	24	25	12 - 29	26	26	18 - 30	25	24	18 - 28
CEC (meq / 100g)	10	10	8 - 13	11	11	9 - 17	12	12	9 - 19	12	11	10 - 18
pH	7.8	7.9	6.6 - 8.1	7.7	7.8	7.1 - 8.0	7.6	7.7	6.5 - 7.9	7.7	7.7	7.1 - 8.0
EC (dS / m)	1.12	0.59	0.36 - 4.02	0.78	0.59	0.36 - 1.38	1.13	0.69	0.50 - 3.67	0.62	0.60	0.27 - 1.08

OM = organic matter. TIC = total inorganic carbon. TOC = total organic carbon. TC = total carbon. TN = total nitrogen. C:N = carbon nitrogen ratio. BS = base saturation. Ca = exchangeable calcium. Mg = exchangeable magnesium. Na = exchangeable sodium. K = exchangeable potassium. ESP = exchangeable sodium percentage. TEC = total exchange capacity. CEC = cation exchange capacity. EC = electrical conductivity.
There were 17 and 15 pairs of quadrats on 10 cm and 20 cm treatments, respectively, within 3 replicates of each application depth.
Lower case letters indicate significant differences between bare and vegetated quadrats at $p < 0.05$.
Statistical analysis was not possible for lower layer EC, exchangeable Na or ESP on LFH mineral soil mix due to inequality of variance.

Table 3.36. Upper layer soil chemical properties of bare and vegetated patches on LFH mineral soil mix at SE dump four years after reclamation.

	Bare			Vegetated		
	Mean	Median	Range	Mean	Median	Range
OM (%)	13.80	11.20	2.13 - 28.60	18.57	16.30	10.70 - 34.10
TIC (%)	0.19	0.12	0.00 - 0.47	0.25	0.21	0.11 - 0.48
TOC (%)	6.90	5.58	1.06 - 14.30	9.30	8.13	5.35 - 17.10
TC (%)	7.08	5.69	1.06 - 14.77	9.55	8.37	5.46 - 17.58
TN (%)	0.24	0.20	0.04 - 0.48	0.33	0.30	0.20 - 0.59
C:N	28.44	28.22	26.10 - 32.18	28.42	28.00	27.30 - 29.80
BS (%)	92	93	85 - 98	95	95	84 - 110
Ca (meq / 100g)	27.0	20.5	9.1 - 53.7	35.0	30.8	20.0 - 54.7
Mg (meq / 100g)	4.1	3.3	1.8 - 7.7	4.9	4.2	3.0 - 7.8
Na (meq / 100g)	0.2	0.2	0.1 - 0.3	0.2	0.2	0.1 - 0.3
K (meq / 100g)	0.4	0.4	0.1 - 1.2	0.6	0.5	0.4 - 0.9
ESP (%)	0.6	0.5	0.4 - 1.0	0.5	0.5	0.4 - 0.7
TEC (meq / 100g)	32	24	11 - 63	41	35	23 - 64
CEC (meq / 100g)	34	28	11 - 67	42	35	26 - 70
pH	6.5	6.6	6.3 - 6.7	6.5	6.6	6.3 - 6.8
EC (dS / m)	0.86	0.72	0.62 - 1.34	0.79	0.64	0.55 - 1.22

OM = organic matter. TIC = total inorganic carbon. TOC = total organic carbon. TC = total carbon. TN = total nitrogen. C:N = carbon nitrogen ratio. BS = base saturation. Ca = exchangeable calcium. Mg = exchangeable magnesium. Na = exchangeable sodium. K = exchangeable potassium. ESP = exchangeable sodium percentage. TEC = total exchange capacity. CEC = cation exchange capacity. EC = electrical conductivity.
There were 7 pairs of quadrats on LFH mineral soil mix within 3 replicates of each cover soil.
There were no significant differences between bare and vegetated quadrats at $p < 0.05$.
Statistical analysis was not possible for upper layer pH on peat mineral soil mix due to inequality of variance.

Table 3.37. Upper layer soil chemical properties of bare and vegetated patches on LFH mineral soil mix at MLSB thirteen years after reclamation.

	Bare						Vegetated					
	Cell 18			Cell 16			Cell 18			Cell 16		
	Mean	Median	Range	Mean	Median	Range	Mean	Median	Range	Mean	Median	Range
OM (%)	13.67	13.95	9.52 - 16.70	4.33	3.21	2.43 - 8.45	14.97	14.15	12.10 - 19.20	8.85	9.66	3.69 - 12.40
TIC (%)	0.14	0.13	0.09 - 0.27	0.31	0.31	0.11 - 0.5	0.12	0.13	0.09 - 0.13	0.23	0.21	0.10 - 0.40
TOC (%)	6.83	6.99	4.76 - 8.33	2.16	1.60	1.21 - 4.22	7.49	7.09	6.05 - 9.60	4.43	4.83	1.85 - 6.22
TC (%)	6.98	7.09	5.03 - 8.47	2.46	1.95	1.62 - 4.33	7.60	7.21	6.14 - 9.73	4.66	5.00	2.25 - 6.40
TN (%)	0.31	0.32	0.19 - 0.37	0.08	0.05	0.02 - 0.21	0.34	0.32	0.29 - 0.47	0.22	0.25	0.07 - 0.30
C:N	22.78	22.52	20.5 26.47	54.60	56.14	20.62-85.50	22.32	21.62	19.61-25.88	23.55	20.92	20.21-32.14
BS (%)	88	89	74 - 100	168	165	91 - 250	84	84	76 - 90	104	106	73 - 130
Ca (meq / 100g)	24.0	23.7	18.0 - 29.4	19.0	18.4	16.0 - 23.2	23.4	24.2	15.2 - 29.6	18.4	18.5	14.9 - 21.5
Mg (meq / 100g)	5.5	5.6	3.8 - 6.7	2.7	2.8	1.4 - 3.8	5.8	5.9	4.6 - 6.8	3.5	3.5	2.7 - 4.4
Na (meq / 100g)	0.1	0.1	0.1 - 0.2	0.1	0.1	0.0 - 0.1	0.1	0.1	0.0 - 0.2	0.0	0.0	0.0 - 0.0
K (meq / 100g)	0.7^{b}	0.6	0.4 - 0.9	0.3^{b}	0.3	0.2 - 0.5	0.8^{a}	0.8	0.6 - 1.1	0.7^{a}	0.6	0.4 - 1.0
ESP (%)	0.4	0.4	0.3 - 0.6	0.5	0.5	0.0 - 1.0	0.2	0.3	0.0 - 0.4	0.0	0.0	0.0 - 0.0
TEC (meq / 100g)	31	30	24 - 37	22	22	20 - 25	30	30	21 - 37	23	23	20 - 25
CEC (meq / 100g)	34	34	30 - 40	15	13	10 - 22	36	35	25 - 45	23	22	18 - 29
pH	6.6	6.7	6.0 - 7.0	7.5	7.7	6.9 - 7.8	6.5	6.4	6.2 - 7.0	6.8	6.8	6.0 - 7.5
EC (dS / m)	0.52	0.52	0.41 - 0.61	0.71	0.53	0.38 - 1.40	0.51	0.51	0.45 - 0.56	0.52	0.48	0.47 - 0.65

OM = organic matter. TIC = total inorganic carbon. TOC = total organic carbon. TC = total carbon. TN = total nitrogen. C:N = carbon nitrogen ratio. BS = base saturation. Ca = exchangeable calcium. Mg = exchangeable magnesium. Na = exchangeable sodium. K = exchangeable potassium. ESP = exchangeable sodium percentage. TEC = total exchange capacity. CEC = cation exchange capacity. EC = electrical conductivity.
There were 4 and 6 pairs of quadrats at Cells 16 and 18, respectively; those at Cell 18 were within 3 cover soil replicates.
Lower case letters indicate significant differences between bare and vegetated quadrats at $p < 0.05$.
Statistical analysis was not possible for upper layer C:N ratio, EC or BS on LFH mineral soil mix due to inequality of variance.

Table 3.38. Lower layer soil chemical properties of bare and vegetated patches on LFH mineral soil mix at SE dump four years after reclamation.

	Bare			Vegetated		
	Mean	Median	Range	Mean	Median	Range
OM (%)	9.47	2.49	1.30 - 29.00	2.62	2.57	1.90 - 3.58
TIC (%)	0.12	0.00	0.00 - 0.40	0.00	0.00	0.00 - 0.00
TOC (%)	4.73	1.25	0.66 - 14.50	1.31	1.28	0.94 - 1.79
TC (%)	4.85	1.25	0.66 - 14.90	1.31	1.28	0.94 - 1.79
TN (%)	0.15	0.04	0.02 - 0.47	0.04	0.04	0.03 - 0.05
C:N	33.60	31.70	22.00 - 44.50	35.33	35.80	30.50 - 42.67
BS (%)	95	97	90 - 100	94	91	85 - 110
Ca (meq / 100g)	20.2	10.1	7.1 - 50.0	8.2	8.0	6.3 - 10.2
Mg (meq / 100g)	3.2	2.6	1.2 - 7.4	1.4	1.3	1.0 - 2.2
Na (meq / 100g)	0.1	0.2	0.0 - 0.2	0.2	0.2	0.1 - 0.2
K (meq / 100g)	0.2	0.2	0.1 - 0.4	0.1	0.1	0.1 - 0.1
ESP (%)	0.9	0.5	0.0 - 2.0	1.5	2.0	0.8 - 2.0
TEC (meq / 100g)	24	13	9 - 58	10	10	8 - 13
CEC (meq / 100g)	25	12	9 - 60	10	10	8 - 12
pH	6.4	6.4	6.0 - 6.7	6.2	6.3	5.7 - 6.5
EC (dS / m)	1.06	0.72	0.34 - 2.02	1.64	1.56	1.05 - 2.53

OM = organic matter. TIC = total inorganic carbon. TOC = total organic carbon. TC = total carbon. TN = total nitrogen. C:N = carbon nitrogen ratio. BS = base saturation. Ca = exchangeable calcium. Mg = exchangeable magnesium. Na = exchangeable sodium. K = exchangeable potassium. ESP = exchangeable sodium percentage. TEC = total exchange capacity. CEC = cation exchange capacity. EC = electrical conductivity.
There were 7 pairs of quadrats on LFH mineral soil mix, respectively, within 3 replicates of each cover soil.
There were no significant differences between bare and vegetated quadrats at $p < 0.05$.
Statistical analysis was not possible for lower layer OM, TIC, TOC, TC, TN or exchangeable Ca, BS, CEC, TEC or ESP on LFH mineral soil mix due to inequality of variance.

Table 3.39. Lower layer soil chemical properties of bare and vegetated patches on LFH mineral soil mix at MLSB thirteen years after reclamation.

	Bare						Vegetated					
	Cell 18			Cell 16			Cell 18			Cell 16		
	Mean	Median	Range	Mean	Median	Range	Mean	Median	Range	Mean	Median	Range
OM%	8.62	4.89	3.79 - 16.80	3.45	3.25	2.19 - 5.09	7.64	4.11	3.47 - 21.50	6.29	3.87	2.64 - 14.80
TIC%	0.26	0.30	0.00 - 0.35	0.35	0.34	0.22 - 0.51	0.33	0.37	0.11 - 0.44	0.38	0.43	0.17 - 0.49
TOC%	3.59	2.23	0.00 - 8.39	1.72	1.63	1.10 - 2.54	3.83	2.06	1.73 - 10.80	3.14	1.94	1.32 - 7.38
TC%	3.85	2.55	0.00 - 8.69	2.08	1.93	1.61 - 2.84	4.15	2.43	2.13 - 11.11	3.52	2.36	1.81 - 7.55
TN%	0.13	0.07	0.00 - 0.30	0.05	0.06	0.02 - 0.08	0.15	0.06	0.03 - 0.52	0.11	0.06	0.02 - 0.31
C:N	28.68	31.55	0.00 - 47.20	49.57	45.08	27.63 - 80.50	39.94	35.50	21.37 - 73.33	51.12	44.80	24.35 - 90.50
BS%	131	130	95 - 160	185	160	140 - 280	137	150	88 - 190	203	220	92 - 280
Ca (meq / 100g)	25.2	21.0	16.9 - 36.1	20.5	19.4	16.1 - 27.2	23.8	22.2	17.5 - 33.7	25.3	25.5	21.0 - 29.4
Mg (meq / 100g)	4.3	3.8	2.4 - 6.2	2.4	2.4	1.7 - 3.2	4.9	4.1	3.0 - 8.0	3.3	3.3	1.7 - 4.7
Na (meq / 100g)	0.2	0.3	0.1 - 0.3	0.1	0.1	0.0 - 0.2	0.2	0.2	0.1 - 0.5	0.1	0.1	0.0 - 0.3
K (meq / 100g)	0.2	0.2	0.2 - 0.3	0.3	0.3	0.2 - 0.3	0.3	0.3	0.2 - 0.3	0.3	0.3	0.2 - 0.5
ESP%	1.0	0.7	0.6 - 2.0	0.8	0.5	0.0 - 2.0	1.4	2.0	0.3 - 2.0	0.9	0.8	0.0 - 2.0
TEC (meq / 100g)	30	25	20 - 43	23	23	19 - 29	29	29	21 - 40	29	29	25 - 34
CEC (meq / 100g)	25	16	15 - 41	13	13	10 - 14	24	16	13 - 45	17	14	11 - 29
pH	7.3	7.4	6.8 - 7.7	7.6	7.6	7.4 - 7.8	7.2	7.5	6.2 - 7.6	7.3	7.6	6.2 - 7.8
EC (dS / m)	0.57	0.62	0.45 - 0.68	1.01	0.61	0.39 - 2.44	0.57	0.50	0.45 - 0.84	0.92	0.52	0.38 - 2.28

OM = organic matter. TIC = total inorganic carbon. TOC = total organic carbon. TC = total carbon. TN = total nitrogen. C:N = carbon nitrogen ratio. BS = base saturation. Ca = exchangeable calcium. Mg = exchangeable magnesium. Na = exchangeable sodium. K = exchangeable potassium. ESP = exchangeable sodium percentage. TEC = total exchange capacity. CEC = cation exchange capacity. EC = electrical conductivity.
There were 4 and 5 pairs of quadrats on Cell 16 and 18, respectively; those at Cell 18 were within 3 cover soil replicates.
There were no significant differences between bare and vegetated quadrats at $p < 0.05$.
Statistical analysis was not possible for lower layer TN or pH on LFH mineral soil mix due to inequality of variance.

Table 3.40. Upper layer soil chemical properties of bare and vegetated patches on peat mineral soil mix at W1 dump eight years after reclamation.

	Bare						Vegetated					
	10 cm peat mineral soil mix			20 cm peat mineral soil mix			10 cm peat mineral soil mix			20 cm peat mineral soil mix		
	Mean	Median	Range	Mean	Median	Range	Mean	Median	Range	Mean	Median	Range
OM (%)	4.77[b]	3.17	1.84 - 11.90	7.11[b]	6.86	2.29 - 16.10	18.58[a]	20.60	7.57 - 25.90	21.85[a]	20.10	8.52 - 50.00
TIC (%)	0.31	0.32	0.06 - 0.50	0.23	0.22	0.00 - 0.65	0.21	0.21	0.13 - 0.27	0.21	0.20	0.10 - 0.47
TOC (%)	2.39[b]	1.58	0.92 - 5.95	3.56[b]	3.44	1.15 - 8.04	9.30[a]	10.30	3.79 - 13.00	10.92[a]	10.00	4.26 - 25.00
TC (%)	2.69[b]	1.87	1.23 - 6.27	3.79[b]	3.49	1.23 - 8.21	9.50[a]	10.51	3.94 - 13.16	11.14[a]	10.12	4.49 - 25.47
TN (%)	0.07[b]	0.04	0.00 - 0.17	0.11[b]	0.12	0.03 - 0.24	0.30[a]	0.32	0.03 - 0.43	0.35[a]	0.33	0.13 - 0.68
C:N ratio	49.04	43.88	27.24-107.00	39.10	36.25	24.60-71.00	38.03	30.91	25.72-131.33	31.55	31.04	25.90-37.46
BS (%)	171[a]	180	96 - 260	136[a]	112	63 - 230	97[b]	98	78 - 120	88[b]	83	66 - 120
Ca (meq / 100g)	21.3[b]	21.3	7.8 - 31.1	21.7[b]	22.4	7.1 - 30.4	33.0[a]	33.6	20.8 - 44.5	31.7[a]	30.5	15.5 - 64.6
Mg (meq / 100g)	4.2[b]	3.4	2.4 - 6.8	4.8[b]	5.2	2.6 - 8.5	9.0[a]	9.0	5.6 - 12.0	9.0[a]	7.9	5.2 - 15.5
Na (meq / 100g)	0.4	0.2	0.1 - 2.0	0.3	0.3	0.1 - 0.5	0.6	0.3	0.1 - 4.2	0.5	0.5	0.2 - 1.1
K (meq / 100g)	0.2[b]	0.2	0.1 - 0.3	0.2[b]	0.2	0.2 - 0.3	0.4[a]	0.4	0.2 - 0.7	0.4[a]	0.4	0.3 - 0.7
ESP (%)	2.5	1.0	0.7 - 13.0	1.3	1.0	0.7 - 3.0	1.3	0.7	0.3 - 7.6	1.2	1.0	0.4 - 2.0
TEC (meq / 100g)	26[b]	26	11 - 36	27[b]	28	12 - 38	43[a]	44	27 - 56	42[a]	39	22 - 81
CEC (meq / 100g)	16[b]	12	10 - 32	22[b]	25	11 - 42	44[a]	47	26 - 57	48[a]	42	22 - 100
pH	7.6[a]	7.6	7.1 - 7.8	7.1[a]	7.4	4.9 - 7.9	6.9[b]	6.9	5.6 - 7.6	6.3[b]	6.2	5.3 - 7.4
EC (dS / m)	1.18	0.81	0.52 - 3.47	0.82	0.79	0.32 - 1.43	0.98	0.86	0.55 - 1.90	0.74	0.70	0.41 - 1.14

OM = organic matter. TIC = total inorganic carbon. TOC = total organic carbon. TC = total carbon. TN = total nitrogen. C:N = carbon nitrogen ratio. BS = base saturation. Ca = exchangeable calcium. Mg = exchangeable magnesium. Na = exchangeable sodium. K = exchangeable potassium. ESP = exchangeable sodium percentage. TEC = total exchange capacity. CEC = cation exchange capacity. EC = electrical conductivity.
There were 15 pairs of quadrats within 3 replicates on 10 cm peat mineral soil mix.
Lower case letters indicate significant differences between bare and vegetated quadrats at $p < 0.05$.
Statistical analysis was not possible for upper layer EC, exchangeable Na or ESP on peat mineral soil mix due to inequality of variance.

Table 3.41. Lower layer soil chemical properties of bare and vegetated patches on peat mineral soil mix at W1 dump eight years after reclamation.

	Bare						Vegetated					
	10 cm peat mineral soil mix			20 cm peat mineral soil mix			10 cm peat mineral soil mix			20 cm peat mineral soil mix		
	Mean	Median	Range	Mean	Median	Range	Mean	Median	Range	Mean	Median	Range
OM (%)	2.54	2.34	1.76 - 3.39	3.75	2.97	2.08 - 16.80	3.55	3.39	1.93 - 6.15	8.43	4.33	1.79 - 59.70
TIC (%)	0.38	0.40	0.14 - 0.50	0.34	0.39	0.00 - 0.49	0.35	0.36	0.16 - 0.49	0.34	0.36	0.08 - 0.76
TOC (%)	1.27	1.17	0.88 - 1.69	1.87	1.49	1.04 - 8.42	1.77	1.69	0.96 - 3.08	4.21	2.17	0.90 - 29.80
TC (%)	1.65	1.55	1.02 - 2.11	2.22	1.91	1.10 - 8.52	2.12	2.03	1.12 - 3.57	4.55	2.61	1.18 - 30.56
TN (%)	0.02	0.02	0.00 - 0.03	0.04	0.03	0.00 - 0.24	0.03	0.03	0.00 - 0.07	0.11	0.05	0.00 - 0.82
C:N	75.08	72.50	47.33-105.50	62.00	58.83	23.17-106.00	68.62	64.00	43.00-119.00	56.84	47.33	34.30-106.50
BS (%)	232[a]	240	150 - 280	203[a]	225	59 - 300	204[b]	200	150 - 270	165[b]	185	86 - 270
Ca (meq / 100g)	22.3	22.8	16.2 - 27.5	21.1	21.6	7.4 - 26.8	22.4	23.3	17.4 - 28.9	25.7	21.2	10.2 - 99.4
Mg (meq / 100g)	3.1	3.1	2.4 - 4.4	3.4	3.1	2.1 - 7.6	3.6	3.7	2.9 - 4.4	4.9	3.6	2.5 - 18.1
Na (meq / 100g)	0.4	0.2	0.1 - 1.9	0.2	0.2	0.1 - 0.3	0.4	0.2	0.1 - 2.2	0.3	0.3	0.1 - 1.0
K (meq / 100g)	0.2	0.2	0.2 - 0.3	0.2	0.2	0.1 - 0.2	0.2	0.2	0.2 - 0.2	0.2	0.2	0.0 - 0.2
ESP (%)	3.1	2.0	1.0 - 15.0	1.8	2.0	0.8 - 3.0	2.9	2.0	0.8 - 16.0	1.8	1.5	1.0 - 4.0
TEC (meq / 100g)	26	26	21 - 34	25	25	12 - 34	27	27	22 - 34	31	27	16 - 119
CEC (meq / 100g)	11	12	9 - 15	14	12	9 - 42	13	13	10 - 17	23	14	10 - 120
pH	7.7	7.7	7.4 - 7.9	7.3	7.7	4.7 - 8.0	7.5	7.6	7.2 - 7.8	7.2	7.4	5.5 - 7.9
EC (dS / m)	1.31	1.03	0.49 - 3.19	0.87	0.71	0.36 - 2.37	1.29	0.83	0.63 - 3.54	0.81	0.77	0.49 - 1.24

OM = organic matter. TIC = total inorganic carbon. TOC = total organic carbon. TC = total carbon. TN = total nitrogen. C:N = carbon nitrogen ratio. BS = base saturation. Ca = exchangeable calcium. Mg = exchangeable magnesium. Na = exchangeable sodium. K = exchangeable potassium. ESP = exchangeable sodium percentage. TEC = total exchange capacity. CEC = cation exchange capacity. EC = electrical conductivity.
There were 15 and 18 pairs of quadrats on 10 cm and 20 cm treatments, respectively, within 3 replicates of each application depth.
Lower case letters indicate significant differences between bare and vegetated quadrats at $p < 0.05$.
Statistical analysis was not possible for lower layer EC, exchangeable Na or ESP on peat mineral soil mix due to inequality of variance.

Table 3.42. Upper layer soil chemical properties of bare and vegetated patches on peat mineral soil mix at SE dump four years after reclamation.

	Bare			Vegetated		
	Mean	Median	Range	Mean	Median	Range
OM (%)	15.83	16.00	7.85 - 22.60	14.36	13.90	10.50 - 20.30
TIC (%)	0.62	0.58	0.32 - 0.96	0.65	0.74	0.18 - 0.95
TOC (%)	7.91	8.00	3.93 - 11.30	7.17	6.94	5.26 - 10.10
TC (%)	8.53	8.73	4.25 - 11.96	7.82	7.66	5.51 - 10.85
TN (%)	0.29	0.30	0.16 - 0.37	0.26	0.25	0.16 - 0.38
C:N	29.56	29.82	25.82 - 33.03	30.89	29.63	25.13 - 41.63
BS (%)	120	120	79 - 160	114	110	100 - 130
Ca (meq / 100g)	48.7	48.6	25.0 - 64.7	52.4	54.2	32.1 - 69.9
Mg (meq / 100g)	5.2	5.1	1.9 - 8.9	5.9	5.7	5.2 - 7.0
Na (meq / 100g)	0.6	0.5	0.2 - 1.2	0.4	0.4	0.2 - 0.6
K (meq / 100g)	0.2	0.2	0.1 - 0.3	0.4	0.3	0.2 - 0.7
ESP (%)	1.1	1.0	0.5 - 2.1	0.7	0.7	0.5 - 1.0
TEC (meq / 100g)	55	55	27 - 73	59	61	38 - 78
CEC (meq / 100g)	45	43	26 - 60	52	54	37 - 69
pH	7.4	7.4	7.2 - 7.6	7.4	7.4	7.1 - 7.7
EC (dS / m)	2.06	2.20	0.65 - 2.86	1.21	1.02	0.81 - 1.72

OM = organic matter. TIC = total inorganic carbon. TOC = total organic carbon. TC = total carbon. TN = total nitrogen. C:N = carbon nitrogen ratio. BS = base saturation. Ca = exchangeable calcium. Mg = exchangeable magnesium. Na = exchangeable sodium. K = exchangeable potassium. ESP = exchangeable sodium percentage. TEC = total exchange capacity. CEC = cation exchange capacity. EC = electrical conductivity.
There were 10 pairs of quadrats on peat mineral soil mix, respectively, within 3 replicates of each cover soil.
There were no significant differences between bare and vegetated quadrats at $p < 0.05$.
Statistical analysis was not possible for upper layer pH on peat mineral soil mix due to inequality of variance.

Table 3.43. Upper layer soil chemical properties of bare and vegetated patches on peat mineral soil mix at MLSB thirteen years after reclamation.

	Bare						Vegetated					
	Cell 18			Cell 16			Cell 18			Cell 16		
	Mean	Median	Range	Mean	Median	Range	Mean	Median	Range	Mean	Median	Range
OM (%)	7.69	7.47	1.50 - 15.70	24.05	24.05	18.90 - 29.20	11.30	9.66	3.15 - 24.50	24.20	24.20	20.10 - 28.30
TIC (%)	0.11	0.09	0.00 - 0.41	0.73	0.73	0.62 - 0.83	0.18	0.19	0.00 - 0.44	0.54	0.54	0.48 - 0.59
TOC (%)	3.85	3.73	0.75 - 7.87	12.04	12.04	9.47 - 14.60	5.64	4.83	1.58 - 12.20	12.10	12.10	10.10 - 14.10
TC (%)	3.96	3.77	0.96 - 7.97	12.76	12.76	10.09 - 15.43	5.83	4.96	2.02 - 12.40	12.64	12.64	10.58 - 14.69
TN (%)	0.19	0.20	0.02 - 0.36	0.62	0.62	0.48 - 0.76	0.31	0.24	0.06 - 0.79	0.62	0.62	0.50 - 0.74
C:N	25.88	19.92	16.00 - 58.00	20.66	20.66	20.30 - 21.02	22.44	21.21	15.70 - 33.67	20.51	20.51	19.85 - 21.16
BS (%)	112	95	74 - 220	120	120	120 - 120	109	97	80 - 190	115	115	110 - 120
Ca (meq / 100g)	20.7	20.4	15.0 - 26.1	53.6	53.6	47.5 - 59.7	28.5	25.4	14.5 - 44.3	51.6	51.6	46.0 - 57.2
Mg (meq / 100g)	4.0	4.3	1.2 - 5.7	5.4	5.4	4.9 - 5.9	4.9	5.5	2.0 - 6.8	5.4	5.4	4.7 - 6.0
Na (meq / 100g)	0.1	0.1	0.0 - 0.1	0.0	0.0	0.0 - 0.0	0.1	0.1	0.0 - 0.1	0.0	0.0	0.0 - 0.0
K (meq / 100g)	0.4	0.5	0.2 - 0.5	0.3	0.3	0.2 - 0.4	0.6	0.5	0.3 - 0.9	0.4	0.4	0.4 - 0.4
ESP (%)	0.3	0.3	0.0 - 0.6	0.0	0.0	0.0 - 0.0	0.2	0.2	0.0 - 0.4	0.0	0.0	0.0 - 0.0
TEC (meq / 100g)	25	24	19 - 32	60	60	53 - 66	34	32	19 - 52	58	58	51 - 64
CEC (meq / 100g)	26	26	10 - 38	49	49	42 - 56	34	31	13 - 61	50	50	43 - 57
pH	6.7	6.8	5.3 - 7.8	7.7	7.7	7.6 - 7.7	6.7	7.0	5.1 - 7.7	7.7	7.7	7.6 - 7.7
EC (dS / m)	0.39	0.36	0.26 - 0.54	0.78	0.78	0.77 - 0.78	0.51	0.59	0.30 - 0.61	0.72	0.72	0.68 - 0.75

OM = organic matter. TIC = total inorganic carbon. TOC = total organic carbon. TC = total carbon. TN = total nitrogen. C:N = carbon nitrogen ratio. BS = base saturation. Ca = exchangeable calcium. Mg = exchangeable magnesium. Na = exchangeable sodium. K = exchangeable potassium. ESP = exchangeable sodium percentage. TEC = total exchange capacity. CEC = cation exchange capacity. EC = electrical conductivity.
There were 2 and 6 pairs of quadrats at Cell 16 and 18, respectively; those at Cell 18 were within 2 cover soil replicates.
There were no significant differences between bare and vegetated quadrats at $p < 0.05$.
Statistical analysis was not possible for upper layer C:N ratio on peat mineral soil mix due to inequality of variance.

Table 3.44. Lower layer soil chemical properties of bare and vegetated patches on peat mineral soil mix at SE dump four years after reclamation.

	Bare			Vegetated		
	Mean	Median	Range	Mean	Median	Range
OM (%)	8.02	5.10	3.11 - 14.10	15.71	18.50	2.89 - 28.10
TIC (%)	0.69	0.61	0.45 - 1.13	0.71	0.73	0.43 - 1.05
TOC (%)	4.01	2.55	1.56 - 7.07	7.85	9.24	1.45 - 14.00
TC (%)	4.71	3.12	2.01 - 8.07	8.56	10.02	2.10 - 15.05
TN (%)	0.12	0.06	0.03 - 0.25	0.28	0.32	0.02 - 0.5
C:N	46.75	49.67	32.28 - 67.00	41.14	30.72	25.96 - 105.00
BS (%)	178	180	120 - 260	150	120	110 - 280
Ca (meq / 100g)	38.0	28.0	17.4 - 66.1	51.9	47.8	21.1 - 80.4
Mg (meq / 100g)	3.6	2.6	1.6 - 6.8	5.3	5.3	1.5 - 8.6
Na (meq / 100g)	0.5	0.4	0.2 - 0.8	0.5	0.3	0.2 - 1.0
K (meq / 100g)	0.1	0.1	0.1 - 0.2	0.2	0.2	0.1 - 0.2
ESP (%)	1.8	2.0	1.0 - 3.0	1.1	1.0	0.7 - 2.0
TEC (meq / 100g)	42	31	19 - 74	58	54	23 - 90
CEC (meq / 100g)	29	17	9 - 63	46	43	9 - 77
pH	7.4	7.5	7.2 - 7.6	7.3	7.2	7.2 - 7.6
EC (dS / m)	2.16	2.45	1.12 - 2.69	1.81	1.91	1.05 - 2.63

OM = organic matter. TIC = total inorganic carbon. TOC = total organic carbon. TC = total carbon. TN = total nitrogen. C:N = carbon nitrogen ratio. BS = base saturation. Ca = exchangeable calcium. Mg = exchangeable magnesium. Na = exchangeable sodium. K = exchangeable potassium. ESP = exchangeable sodium percentage. TEC = total exchange capacity. CEC = cation exchange capacity. EC = electrical conductivity.
There were 10 pairs of quadrats on peat mineral soil mix, respectively, within 3 replicates of each cover soil.
There were no significant differences between bare and vegetated quadrats at $p < 0.05$.
Statistical analysis was not possible for lower layer OM, TIC, TOC, TC, TN or exchangeable Ca, BS, CEC, TEC or ESP on LFH mineral soil mix due to inequality of variance.

Table 3.45. Lower layer soil chemical properties of bare and vegetated patches on peat mineral soil mix at MLSB thirteen years after reclamation.

	Bare						Vegetated					
	Cell 18			Cell 16			Cell 18			Cell 16		
	Mean	Median	Range	Mean	Median	Range	Mean	Median	Range	Mean	Median	Range
OM (%)	2.56	2.31	0.69 - 4.91	2.79	2.79	2.43 - 3.15	3.86	2.91	2.20 - 9.44	2.90	2.90	2.65 - 3.15
TIC (%)	0.17	0.15	0.00 - 0.4	0.42	0.42	0.40 - 0.44	0.21	0.18	0.00 - 0.46	0.43	0.43	0.40 - 0.45
TOC (%)	1.28	1.16	0.34 - 2.46	1.40	1.40	1.22 - 1.58	1.93	1.45	1.10 - 4.72	1.45	1.45	1.32 - 1.58
TC (%)	1.45	1.53	0.34 - 2.46	1.82	1.82	1.66 - 1.98	2.14	1.71	1.21 - 4.72	1.88	1.88	1.77 - 1.98
TN (%)	0.04	0.03	0.00 - 0.11	0.03	0.03	0.02 - 0.03	0.06	0.04	0.03 - 0.19	0.04	0.04	0.04 - 0.04
C:N	43.76	43.00	22.36 - 70.00	74.50	74.50	66.00 - 83.00	41.14	40.33	24.84 - 56.33	46.88	46.88	44.25 - 49.50
BS (%)	152	130	54 - 280	300	300	290 - 310	186	150	76 - 340	285	285	260 - 310
Ca (meq / 100g)	17.5	18.7	1.8 - 28.9	34.0	34.0	33.5 - 34.4	20.9	17.8	11.5 - 34.2	30.1	30.1	26.8 - 33.3
Mg (meq / 100g)	2.2	2.2	0.3 - 3.6	3.1	3.1	2.5 - 3.7	2.2	1.8	1.4 - 4.0	2.6	2.6	2.2 - 2.9
Na (meq / 100g)	0.1	0.2	0.0 - 0.2	0.0	0.0	0.0 - 0.0	0.1	0.1	0.0 - 0.2	0.2	0.2	0.1 - 0.2
K (meq / 100g)	0.2	0.2	0.0 - 0.3	0.3	0.3	0.2 - 0.3	0.2	0.2	0.1 - 0.3	0.2	0.2	0.2 - 0.2
ESP (%)	0.8	0.9	0.0 - 1.0	0.0	0.0	0.0 - 0.0	0.6	0.7	0.0 - 1.0	1.5	1.5	0.9 - 2.0
TEC (meq / 100g)	20	23	2 - 31	37	37	37 - 37	23	21	13 - 37	33	33	30 - 36
CEC (meq / 100g)	13	13	0 - 24	13	13	12 - 13	15	12	8 - 31	12	12	11 - 12
pH	6.9	7.3	5.2 - 7.5	7.5	7.5	7.5 - 7.5	7.1	7.4	5.5 - 7.6	7.5	7.5	7.5 - 7.5
EC (dS / m)	1.23	1.29	0.20 - 2.30	2.58	2.58	2.53 - 2.62	1.07	0.45	0.33 - 2.53	2.31	2.31	2.13 - 2.49

OM = organic matter. TIC = total inorganic carbon. TOC = total organic carbon. TC = total carbon. TN = total nitrogen. C:N = carbon nitrogen ratio. BS = base saturation. Ca = exchangeable calcium. Mg = exchangeable magnesium. Na = exchangeable sodium. K = exchangeable potassium. ESP = exchangeable sodium percentage. TEC = total exchange capacity. CEC = cation exchange capacity. EC = electrical conductivity.
There were 2 and 6 pairs of quadrats at Cell 16 and 18, respectively; those at Cell 18 were within 2 cover soil replicates.
There were no significant differences between bare and vegetated quadrats at $p < 0.05$.
Statistical analysis was not possible for lower layer OM, TOC, TC, TN or pH on peat mineral soil mix due to inequality of variance.

Table 3.46. Lower layer soil physical properties of bare and vegetated patches LFH mineral soil mix at W1 dump eight years after reclamation.

	Bare			Vegetated		
	Mean	Median	Range	Mean	Median	Range
10 cm LFH mineral soil mix						
Sand (%)	37.4	35.4	25.0 - 56.4	34.4	35.0	21.4 - 44.4
Silt (%)	30.7	31.0	17.6 - 40.6	32.4	33.0	22.0 - 40.0
Clay (%)	31.9	30.6	24.0 - 42.0	33.3	33.6	23.2 - 50.6
Texture	Clay loam	Clay loam	-	Clay loam	Clay loam	-
20 cm LFH mineral soil mix						
Sand (%)	39.3	36.4	28.4 - 55.0	35.6	35.4	28.0 - 48.8
Silt (%)	28.2	29.6	11.4 - 35.8	31.5	30.6	19.2 - 41.6
Clay (%)	32.5	34.0	19.8 - 46.2	32.9	32.4	28.0 - 41.4
Texture	Clay loam	Clay loam	-	Clay loam	Clay loam	-

There were 17 and 15 pairs of quadrats on the 10 and 20 cm treatments, respectively, within 3 replicates of each application depth. There were no significant differences between bare and vegetated quadrats at $p < 0.05$.

Table 3.47. Lower layer soil physical properties of bare and vegetated patches on two cover soils at SE dump four years after reclamation.

	Bare			Vegetated		
	Mean	Median	Range	Mean	Median	Range
LFH mineral soil mix						
Sand (%)	50.0	50.0	44.8-56.4	51.9	52.0	50.0-54.0
Silt (%)	33.2	32.0	24.2-40.0	32.7	33.6	29.0-34.2
Clay (%)	16.7	14.0	10.4-31.0	15.4	14.4	13.6-21.0
Texture	Loam	Loam	-	Loam	Loam	-
Peat mineral soil mix						
Sand (%)	55.8	54.8	49.0-64.6	52.4	50.7	46.0-58.8
Silt (%)	26.5	24.2	20.4-34.3	29.2	28.3	23.2-36.0
Clay (%)	17.8	17.6	15.0-21.6	18.5	18.0	14.0-22.4
Texture	Sandy loam	Sandy loam	-	Loam	Loam	-

Water retention is reported in gravimetric water content (%).
There were 7 and 10 pairs of quadrats on LFH mineral soil mix and peat mineral soil mix, respectively, within 3 cover soil replicates except for bulk density and volumetric water content (quadrats were removed from analysis).
There were no significant differences between bare and vegetated quadrats at $p < 0.05$.

Table 3.48. Lower layer soil physical properties of bare and vegetated patches on LFH mineral soil mix at two sites at MLSB thirteen years after reclamation.

	Bare			Vegetated		
	Mean	Median	Range	Mean	Median	Range
Cell 18						
Sand (%)	42.1	40.0	31.4 - 52.4	43.2	36.4	34.4 - 56.0
Silt (%)	24.6	23.2	22.4 - 30.6	23.4	23.6	19.2 - 28.2
Clay (%)	33.2	37.0	23.6 - 40.0	33.4	37.0	21.0 - 46.4
Texture	Clay loam	Clay loam	-	Clay loam	Clay loam	-
Cell 16						
Sand (%)	37.6	36.6	28.4 - 48.8	33.1	33.1	29.4 - 36.8
Silt (%)	26.6	26.2	24.2 - 29.6	30.8	27.4	26.8 - 41.6
Clay (%)	35.9	35.0	27.0 - 46.4	36.1	39.2	23.0 - 43.0
Texture	Clay loam	Clay loam	-	Clay loam	Clay loam	-

Water retention is reported in gravimetric water content (%).
There were 5 pairs of quadrats within 3 cover soil replicates at Cell 18 and 4 pairs of quadrats within 1 cover soil replicate at Cell 16, except for bulk density and volumetric water content (quadrats were removed from analysis).
There were no significant differences between bare and vegetated quadrats at $p < 0.05$.

Table 3.49. Lower layer soil physical properties of bare and vegetated patches on peat mineral soil mix at W1 dump eight years after reclamation.

	Bare			Vegetated		
	Mean	Median	Range	Mean	Median	Range
10 cm peat mineral soil mix						
Sand (%)	35.3	34.0	29.0 - 43.0	34.1	34.0	28.4 - 39.0
Silt (%)	31.8	31.4	26.4 - 37.4	32.7	33.4	27.4 - 38.0
Clay (%)	32.9	31.6	27.6 - 41.6	33.2	33.6	25.6 - 39.2
Texture	Clay loam	Clay loam	-	Clay loam	Clay loam	-
20 cm peat mineral soil mix						
Sand (%)	34.6	34.7	24.0 - 44.0	35.9	34.5	28.4 - 50.6
Silt (%)	31.4	33.1	22.4 - 37.4	33.0	33.7	11.8 - 43.5
Clay (%)	34.0	32.6	23.6 - 52.0	31.1	31.7	13.0 - 38.0
Texture	Clay loam	Clay loam	-	Clay loam	Clay loam	-

There were 15 and 18 pairs of quadrats on 10 cm and 20 cm treatments, respectively, within 3 replicates of each application depth. There were no significant differences between bare and vegetated quadrats at $p < 0.05$.

Table 3.50. Lower layer soil physical properties of bare and vegetated patches on peat mineral soil mix at two sites at MLSB thirteen years after reclamation.

	Bare			Vegetated		
	Mean	Median	Range	Mean	Median	Range
Cell 18						
Sand (%)	48.7	53.1	20.4 - 90.8	50.9	52.7	22.0 - 72.8
Silt (%)	17.2	18.9	2.2 - 27.6	19.2	19.5	11.2 - 25.6
Clay (%)	34.1	29.0	7.0 - 61.0	29.9	28.8	16.0 - 52.4
Texture	Sandy clay loam	Sandy clay loam	-	Sandy clay loam	Sandy clay loam	-
Cell 16						
Sand (%)	36.2	36.2	34.0 - 38.4	38.4	38.4	36.4 - 40.4
Silt (%)	23.6	23.6	23.2 - 24.0	25.6	25.6	23.6 - 27.6
Clay (%)	40.2	40.2	38.4 - 42.0	36.0	36.0	36.0 - 36.0
Texture	Clay	Clay	-	Clay loam	Clay loam	-

Water retention is reported in gravimetric water content (%).
There were 6 pairs of quadrats within 2 cover soil replicates at Cell 18 and 2 pairs of quadrats within 1 cover soil replicate at Cell 16, except for bulk density and volumetric water content (quadrats were removed from analysis).
There were no significant differences between bare and vegetated quadrats at $p < 0.05$.
Statistical analysis was not possible for lower layer silt and clay content on peat mineral soil mix due to inequality of variance.

Table 3.51. Maximum penetration resistance and depth at which it was encountered at bare and vegetated patches on two application depths of LFH mineral soil mix at W1 dump eight years after reclamation.

	Bare			Vegetated		
	Mean	Median	Range	Mean	Median	Range
10 cm LFH mineral soil mix						
Maximum penetration resistance (MPa)	3.2	3.2	1.4 - 5.3	3.7	3.8	1.4 - 5.8
Maximum depth (cm)	21	22	10 - 28	23	23	7 - 30
20 cm LFH mineral soil mix						
Maximum penetration resistance (MPa)	3.4	3.2	2.0 - 5.9	3.7	3.7	2.3 - 5.2
Maximum depth (cm)	21	23	10 - 28	22	23	17 - 28

Three readings were taken in 42 pairs of quadrats on LFH mineral soil mix (10 and 20 cm combined) within 3 replicates of each application depth.
There were no significant differences between bare and vegetated quadrats at $p < 0.05$.

Table 3.52. Maximum penetration resistance and depth at which it was encountered at bare and vegetated patches on LFH mineral soil mix at two sites at MLSB in thirteen years after reclamation.

	Bare			Vegetated		
	Mean	Median	Range	Mean	Median	Range
Cell 18						
Maximum penetration resistance (MPa)	4.0	4.1	2.6 - 5.3	4.3	4.8	2.0 - 5.2
Maximum depth (cm)	26	27	20 - 30	23	23	17 - 28
Cell 16						
Maximum penetration resistance (MPa)	2.7	3.0	1.6 - 3.1	3.9	4.2	2.0 - 5.1
Maximum depth (cm)	18	20	7 - 25	21	21	13 - 28

Three readings were taken in 4 pairs of quadrats at Cell 16 within 1 cover soil replicate and at 6 pairs of quadrats at Cell 18 within 3 cover soil replicates.
There were no significant differences between bare and vegetated quadrats at $p < 0.05$.

Table 3.53. Maximum penetration resistance and depth at which it was encountered at bare and vegetated patches on two application depths of peat mineral soil mix at W1 dump eight years after reclamation.

	Bare			Vegetated		
	Mean	Median	Range	Mean	Median	Range
10 cm peat mineral soil mix						
Maximum penetration resistance (MPa)	3.5	4.0	1.3 - 5.3	3.6	3.5	1.8 - 5.9
Maximum depth (cm)	18[b]	20	5 - 30	25[a]	25	17 - 30
20 cm peat mineral soil mix						
Maximum penetration resistance (MPa)	3.6	3.9	2.3 - 5.1	3.4	3.5	1.9 - 4.6
Maximum depth (cm)	22[b]	20	15 - 30	23[a]	25	12 - 30

Three readings were taken in 21 and 19 pairs of quadrats on 10 cm and 20 cm treatments, respectively, within 3 replicates of each application depth.
Lower case letters indicate significant differences between bare and vegetated quadrats at $p < 0.05$.

Table 3.54. Maximum penetration resistance and depth at which it was encountered at bare and vegetated patches on peat mineral soil mix at two sites at MLSB thirteen years after reclamation.

	Bare			Vegetated		
	Mean	Median	Range	Mean	Median	Range
Cell 18						
Maximum penetration resistance (MPa)	4.6	4.8	3.0 - 5.8	4.5	4.3	3.8 - 5.3
Maximum depth (cm)	25	26	20 - 28	24	26	18 - 28
Cell 16						
Maximum penetration resistance (MPa)	4.3	4.3	3.7 - 4.9	4.5	4.5	3.9 - 5.1
Maximum depth (cm)	23	23	22 - 25	26	26	22 - 30

Three readings were taken in 2 pairs of quadrats at Cell 16 within 1 cover soil replicate and at 6 pairs of quadrats at Cell 18 within 2 cover soil replicates. There were no significant differences between bare and vegetated quadrats at $p < 0.05$.

Table 3.55. Upper layer soil chemical properties in 2004 (initial conditions) and on bare and vegetated patches in 2011 on LFH mineral soil mix at W1 dump.

	10 cm LFH mineral soil mix			20 cm LFH mineral soil mix		
	Mean	Median	Range	Mean	Median	Range
Initial conditions						
Total organic carbon (%)	4.1[A]	3.7	3.3 - 5.2	5.6[A]	6.0	4.5 - 6.2
Organic matter (%)	7.1[A]	6.5	5.8 - 8.9	11.3[A]	10.7	7.7 - 15.4
Total nitrogen (%)	0.17[A]	0.15	0.13 - 0.24	0.32[A]	0.29	0.22 - 0.45
pH	6.2[B/b]	6.2	6.1 - 6.4	6.2[b]	6.1	6.1 - 6.3
Bare patches						
Total organic carbon (%)	1.4[B]	1.4	1.3 - 1.5	2.1[B]	2.3	1.4 - 2.6
Organic matter (%)	2.8[B]	2.7	2.6 - 2.9	4.2[B]	4.6	2.8 - 5.2
Total nitrogen (%)	0.04[B]	0.04	0.03 - 0.05	0.07[B]	0.08	0.04 - 0.10
pH	7.6[A]	7.8	7.2 - 7.9	7.2	7.2	6.6 - 7.9
Vegetated patches						
Total organic carbon (%)	5.1	4.9	3.4 - 7.2	5.8	6.5	3.1 - 7.7
Organic matter (%)	10.3	9.7	6.7 - 14.4	11.6	13.0	6.3 - 15.4
Total nitrogen (%)	0.25	0.20	0.14 - 0.41	0.27	0.32	0.13 - 0.36
pH	7.1[a]	7.1	7.0 - 7.1	7.2[a]	7.3	6.8 - 7.4

Initial soil data was collected by Mackenzie (2006); 14 samples were collected from each of 3 replicates of 10 cm and 20 cm treatments (total of 42 samples for each application depth). In 2011 5 to 7 samples were collected from each of 3 replicates of 10 cm and 20 cm treatments (total of 17 and 15 for 10 cm and 20 cm treatments, respectively).
Upper case letters indicate significant differences between initial conditions and bare patches and lower case letters indicate significant differences between initial conditions and vegetated patches ($p < 0.05$ or $p < 0.1$ for non-parametric tests); 10 and 20 cm treatments were analyzed separately.

Table 3.56. Upper layer soil chemical properties in 2004 (initial conditions) and in 2011 on bare and vegetated patches on peat mineral soil mix at W1 dump.

	10 cm peat mineral soil mix			20 cm peat mineral soil mix		
	Mean	Median	Range	Mean	Median	Range
Initial conditions						
Total organic carbon (%)	$7.8^{A/b}$	7.7	7.6 - 8.1	8.1^{A}	8.6	6.6 - 9.2
Organic matter (%)	$15.1^{A/b}$	15.7	13.6 - 16.0	15.5^{A}	17.0	12.0 - 17.4
Total nitrogen (%)	0.26^{A}	0.27	0.26 - 0.27	0.28^{A}	0.29	0.24 - 0.32
pH	$6.1^{B/b}$	6.0	5.9 - 6.4	5.8^{B}	5.7	5.7 - 6.0
Bare patches						
Total organic carbon (%)	2.4^{B}	2.1	1.9 - 3.2	3.4^{B}	3.4	2.4 - 4.5
Organic matter (%)	4.8^{B}	4.1	3.8 - 6.3	6.9^{B}	6.8	4.8 - 9.1
Total nitrogen (%)	0.07^{B}	0.06	0.05 - 0.09	0.10^{B}	0.10	0.08 - 0.13
pH	7.6^{A}	7.5	7.5 - 7.6	7.0^{A}	7.0	6.6 - 7.5
Vegetated patches						
Total organic carbon (%)	9.3^{a}	9.3	8.5 - 10.1	10.6	11.1	7.3 - 13.3
Organic matter (%)	18.6^{a}	18.6	17.1 - 20.1	21.2	22.3	14.7 - 26.5
Total nitrogen (%)	0.30	0.30	0.27 - 0.33	0.34	0.36	0.26 - 0.42
pH	6.9^{a}	6.9	6.7 - 7.2	6.3	6.3	5.9 - 6.5

Initial soil data was collected by Mackenzie (2006); 14 samples were collected from each of 3 replicates of 10 cm and 20 cm treatments (total of 42 samples for each application depth). In 2011 5 to 7 samples were collected from each of 3 replicates of 10 cm and 20 cm treatments (total of 15 and 19 for 10 cm and 20 cm treatments, respectively).
Upper case letters indicate significant differences between initial conditions and bare patches and lower case letters indicate significant differences between initial conditions and vegetated patches ($p < 0.05$ or $p < 0.1$ for non-parametric tests); 10 and 20 cm treatments were analyzed separately.

Table 3.57. Upper layer soil quality at bare and vegetated patches on LFH mineral soil mix at W1 dump eight years after reclamation.

		Bare				Vegetated			
		10 cm		20 cm		10 cm		20 cm	
Parameter	Criteria or threshold	Mean	Rating	Mean	Rating	Mean	Rating	Mean	Rating
TOC (%)	Good : > 2; Fair : 1 - 2	1.39	Fair	2.09	Good	4.93	Good	5.77	Good
CEC (meq / 100g)	Medium : 5 - 30 High : > 30	10	Medium	15	Medium	29	Medium / high	28	Medium / high
pH	Good : 5.0 - 6.5 Fair : 4.0 - 5.0 or 6.5 - 7.5 Poor : 3.5 - 4.0 or 7.5 - 9.0	7.6	Poor	7.2	Fair	7.1	Fair	7.2	Fair
EC (dS / m)	Good : < 2; Fair : 2 - 4	1.43	Good	1.06	Good	1.12	Good	0.64	Good
Texture	Good : FSL, VFSL, L, SiL, SL Fair : CL, SCL, SiCL	Clay loam	Fair	Clay loam	Fair	Loam	Good	Loam	Good
C:N ratio	25:1	53.96	Above threshold	42.77	Above threshold	22.68	Below threshold	26.11	Below threshold
BS (%)	100	233	Above threshold	160	Above threshold	113	Above threshold	118	Above threshold
ESP (%)	15	5.5	Below threshold	1.4	Below threshold	1.8	Below threshold	0.7	Below threshold
BD (g / cm^3)	1.6 for loam and clay loam	1.35	Below threshold	1.26	Below threshold	0.94	Below threshold	0.96	Below threshold
PR (MPa)	2	3.2	Above threshold	3.4	Above threshold	3.7	Above threshold	3.7	Above threshold

Table 3.58. Lower layer soil quality at bare and vegetated patches on LFH mineral soil mix at W1 dump eight years after reclamation.

		Bare				Vegetated			
		10 cm		20 cm		10 cm		20 cm	
Parameter	Criteria or threshold	Mean	Rating	Mean	Rating	Mean	Rating	Mean	Rating
TOC (%)	Good : > 2 Fair : 1 - 2	1.30	Fair	1.28	Fair	1.71	Fair	1.61	Fair
CEC (meq / 100g)	Medium : 5 - 30 High : > 30	10	Medium	11	Medium	12	Medium	12	Medium
pH	Good : 5.0 - 7.0 Fair : 4.0 - 5.0 or 7.0 – 8.0 Poor : 3.5 - 4.5 or 8.0 - 9.0	7.8	Fair	7.7	Fair	7.6	Fair	7.7	Fair
EC (dS / m)	Good : < 3 Fair : 3 - 5	1.12	Good	0.78	Good	1.13	Good	0.62	Good
Texture	Good : FSL, VFSL, L, SiL, SL Fair : CL, SiC, SiCL	Clay loam	Fair	Clay loam	Fair	Clay loam	Fair	Clay loam	Fair
C:N ratio	25:1	73.20	Above threshold	64.81	Above threshold	61.67	Above threshold	62.37	Above threshold
BS (%)	100	255	Above threshold	216	Above threshold	221	Above threshold	212	Above threshold
ESP (%)	15	4.7	Below threshold	1.5	Below threshold	4.5	Below threshold	1.2	Below threshold

Subsurface ratings were used for lower layer parameters except in the case of TOC.

Table 3.59. Upper layer soil quality at bare and vegetated patches on peat mineral soil mix at W1 dump eight years after reclamation.

		Bare				Vegetated			
		10 cm		20 cm		10 cm		20 cm	
Parameter	Criteria or threshold	Mean	Rating	Mean	Rating	Mean	Rating	Mean	Rating
TOC (%)	Good : > 2; Fair : 1 - 2	2.39	Good	3.56	Good	9.30	Good	10.92	Good
CEC (meq / 100g)	Medium : 5 - 30 High : > 30	16	Medium	22	Medium	44	High	48	High
pH	Good : 5.0 - 7.0 Fair : 4.0 - 5.0 or 7.0 - 8.0 Poor : 3.5 - 4.5 or 8.0 - 9.0	7.6	Poor	7.1	Fair	6.9	Fair	6.3	Good
EC (dS / m)	Good : < 2; Fair : 2 - 4	1.18	Good	0.82	Good	0.98	Good	0.74	Good
Texture	Good : FSL, VFSL, L, SiL, SL Fair : CL, SCL, SiCL	Clay loam	Fair	Clay loam	Fair	Clay loam	Fair	Clay loam	Fair
C:N ratio	25:1	49.04	Above threshold	39.10	Above threshold	38.03	Above threshold	31.55	Above threshold
BS (%)	100	171	Above threshold	136	Above threshold	97	Below threshold	88	Below threshold
ESP (%)	15	2.5	Below threshold	1.3	Below threshold	1.3	Below threshold	1.2	Below threshold
BD (g / cm^3)	1.6 for loam and clay loam	1.27	Below threshold	1.07	Below threshold	0.72	Below threshold	0.64	Below threshold
PR (MPa)	2	3.5	Above threshold	3.6	Above threshold	3.6	Above threshold	3.4	Above threshold

Table 3.60. Lower layer soil quality at bare and vegetated patches on peat mineral soil mix at W1 dump eight years after reclamation.

		Bare				Vegetated			
		10 cm		20 cm		10 cm		20 cm	
Parameter	Criteria	Mean	Rating	Mean	Rating	Mean	Rating	Mean	Rating
TOC (%)	Good : > 2; Fair : 1 - 2	1.27	Fair	1.87	Fair	1.77	Fair	4.21	Good
CEC (meq / 100g)	Medium : 5 - 30 High : > 30	11	Medium	14	Medium	13	Medium	23	Medium
pH	Good : 5.0 - 7.0 Fair : 4.0 - 5.0 or 7.0 - 8.0 Poor : 3.5 - 4.5 or 8.0 - 9.0	7.7	Fair	7.3	Fair	7.5	Fair	7.2	Fair
EC (dS / m)	Good : < 3 Fair : 3 - 5	1.31	Good	0.87	Good	1.29	Good	0.81	Good
Texture	Good : FSL, VFSL, L, SiL, SL Fair : CL, SiC, SiCL	Clay loam	Fair	Clay loam	Fair	Clay loam	Fair	Clay loam	Fair
C:N ratio	25:1	75.08	Above threshold	62.00	Above threshold	68.62	Above threshold	56.84	Above threshold
BS (%)	100	232	Above threshold	203	Above threshold	204	Above threshold	165	Above threshold
ESP (%)	15	3.1	Below threshold	1.8	Below threshold	2.9	Below threshold	1.8	Below threshold

Subsurface ratings were used for lower layer parameters except in the case of TOC.

Table 3.61. Upper layer soil quality at bare and vegetated patches on LFH mineral soil mix at SE dump four years after reclamation.

		Bare		Vegetated	
Parameter	Criteria or threshold	Mean	Rating	Mean	Rating
TOC (%)	Good : > 2 Fair : 1 - 2	6.90	Good	9.30	Good
CEC (meq / 100g)	Medium : 5 - 30 High : > 30	34	High	42	High
pH	Good : 5.0 - 6.5 Fair : 4.0 - 5.0 or 6.5 - 7.5 Poor: 3.5 - 4.5 or 8.0 - 9.0	6.5	Good / fair	6.5	Good / fair
EC (dS / m)	Good : <2 Fair : 2 - 4	0.86	Good	0.79	Good
Texture	Good : FSL, VFSL, L, SiL, SL Fair : CL, SCL, SiCL	Loam	Good	Loam	Good
C:N ratio	25:1	28.44	Above threshold	28.42	Above threshold
BS (%)	100	92	Below threshold	95	Below threshold
ESP (%)	15	0.6	Below threshold	0.5	Below threshold
BD (g / cm^3)	1.6 for loam and clay loam	0.63	Below threshold	0.63	Below threshold

Table 3.62. Lower layer soil quality at bare and vegetated patches on LFH mineral soil mix at SE dump four years after reclamation.

		Bare		Vegetated	
Parameter	Criteria or threshold	Mean	Rating	Mean	Rating
TOC (%)	Good : > 2 Fair : 1 - 2	4.73	Good	1.31	Fair
CEC (meq / 100g)	Medium : 5 - 30 High : > 30	25	Medium	10	Medium
pH	Good : 5.0 - 7.0 Fair : 4.0 - 5.0 or 7.0 - 8.0	6.4	Good	6.2	Good
EC (dS / m)	Good : < 3 Fair : 3 - 5	1.06	Good	1.64	Good
Texture	Good : FSL, VFSL, L, SiL, SL Fair : CL, SiC, SiCL	Loam	Good	Loam	Good
C:N	25:1	33.60	Above threshold	35.33	Above threshold
BS (%)	100	95	Below threshold	94	Below threshold
ESP (%)	15	0.9	Below threshold	1.5	Below threshold

Subsurface ratings were used for lower layer parameters except in the case of TOC.

Table 3.63. Upper layer soil quality at bare and vegetated patches on peat mineral soil mix at SE dump four years after reclamation.

		Bare		Vegetated	
Parameter	Criteria or threshold	Mean	Rating	Mean	Rating
TOC (%)	Good : > 2 Fair : 1 - 2	7.91	Good	7.17	Good
CEC (meq / 100g)	Medium : 5 - 30 High : > 30	45	High	52	High
pH	Good : 5.0 - 6.5 Fair : 4.0 - 5.0 or 6.5 - 7.5	7.4	Fair	7.4	Fair
EC (dS / m)	Good : < 2 Fair : 2 - 4	2.06	Fair	1.21	Good
Texture	Good :FSL, VFSL, L, SiL, SL Fair : CL, SCL, SiCL	Loam	Good	Loam	Good
C:N ratio	25:1	29.56	Above threshold	30.89	Above threshold
BS (%)	100	120	Above threshold	114	Above threshold
ESP (%)	15	1.1	Below threshold	0.7	Below threshold
BD (g / cm^3)	1.6 for loam and clay loam	1.06	Below threshold	0.86	Below threshold

Table 3.64. Lower layer soil quality at bare and vegetated patches on peat mineral soil mix at SE dump four years after reclamation.

		Bare		Vegetated	
Parameter	Criteria or threshold	Mean	Rating	Mean	Rating
TOC (%)	Good : > 2 Fair : 1 - 2	4.01	Good	7.85	Good
CEC (meq / 100g)	Medium: 5 - 30 High : > 30	29	Medium / high	46	High
pH	Good : 5.0 - 7.0 Fair : 4.0 - 5.0 or 7.0 - 8.0	7.4	Fair	7.3	Fair
EC (dS / m)	Good : <3 Fair : 3 - 5	2.16	Good	1.81	Good
Texture	Good : FSL, VFSL, L, SiL, SL Fair : CL, SiC, SiCL	Sandy loam	Good	Loam	Good
C:N ratio	25:1	46.75	Above threshold	41.14	Above threshold
BS (%)	100	178	Above threshold	150	Above threshold
ESP (%)	15	1.8	Below threshold	1.1	Below threshold

Subsurface ratings were used for lower layer parameters except in the case of TOC.

Table 3.65. Upper layer soil quality at bare and vegetated patches on LFH mineral soil mix at MLSB thirteen years after reclamation.

		Bare				Vegetated			
		Cell 18		Cell 16		Cell 18		Cell 16	
Parameter	Criteria or threshold	Mean	Rating	Mean	Rating	Mean	Rating	Mean	Rating
TOC (%)	Good : > 2; Fair : 1 - 2	6.83	Good	2.16	Good	7.49	Good	4.43	Good
CEC (meq / 100g)	Medium: 5 - 30 High : > 30	34	High	15	Medium	36	High	23	Medium
pH	Good : 5.0 - 6.5 Fair : 4.0 - 5.0 or 6.5 - 7.5 Poor : 3.5 - 4.0 or 7.5 - 9.0	6.6	Fair	7.5	Fair / poor	6.5	Good / fair	6.8	Fair
EC (dS / m)	Good : < 2; Fair : 2 - 4	0.52	Good	0.71	Good	0.51	Good	0.52	Good
Texture	Good : FSL, VFSL, L, SiL, SL Fair : CL, SCL, SiCL	Clay loam	Fair	Clay loam	Fair	Clay loam	Fair	Clay loam	Fair
C:N ratio	25:1	22.78	Below threshold	54.60	Above threshold	22.32	Below threshold	23.55	Below threshold
BS (%)	100	88	Below threshold	168	Above threshold	84	Below threshold	104	Above threshold
ESP (%)	15	0.4	Below threshold	0.5	Below threshold	0.2	Below threshold	0.0	Below threshold
BD (g / cm^3)	1.6 for loam and clay loam	1.07	Below threshold	1.07	Below threshold	0.76	Below threshold	0.87	Below threshold
PR (MPa)	2	4.0	Above threshold	2.7	Above threshold	4.3	Above threshold	3.9	Above threshold

Table 3.66. Lower layer soil quality at bare and vegetated patches on LFH mineral soil mix at MLSB thirteen years after reclamation.

		Bare				Vegetated			
		Cell 18		Cell 16		Cell 18		Cell 16	
Parameter	Criteria or threshold	Mean	Rating	Mean	Rating	Mean	Rating	Mean	Rating
TOC (%)	Good : > 2 Fair : 1 - 2	3.59	Good	1.72	Fair	3.83	Good	3.14	Good
CEC (meq / 100g)	Medium : 5 - 30 High : > 30	25	Medium	13	Medium	24	Medium	17	Medium
pH	Good : 5.0 - 7.0 Fair : 4.0 - 5.0 or 7.0 - 8.0 Poor : 3.5 - 4.5 or 8.0 - 9.0	7.3	Fair	7.6	Fair	7.2	Fair	7.3	Fair
EC (dS / m)	Good : < 3 Fair : 3 - 5	0.57	Good	1.01	Good	0.57	Good	0.92	Good
Texture	Good : FSL, VFSL, L, SiL, SL Fair : CL, SiC, SiCL	Clay loam	Fair	Clay loam	Fair	Clay loam	Fair	Clay loam	Fair
C:N ratio	25:1	28.68	Above threshold	49.57	Above threshold	39.94	Above threshold	51.12	Above threshold
BS (%)	100	131	Above threshold	185	Above threshold	137	Above threshold	203	Above threshold
ESP (%)	15	1.0	Below threshold	0.8	Below threshold	1.4	Below threshold	0.9	Below threshold

Subsurface (lower lift ratings were used for lower layer parameters except in the case of TOC.

Table 3.67. Upper layer soil quality at bare and vegetated patches on peat mineral soil mix at MLSB thirteen years after reclamation.

		Bare				Vegetated			
		Cell 18		Cell 16		Cell 18		Cell 16	
Parameter	Criteria or threshold	Mean	Rating	Mean	Rating	Mean	Rating	Mean	Rating
TOC (%)	Good : > 2; Fair : 1 - 2	3.85	Good	12.04	Good	5.64	Good	12.10	Good
CEC (meq / 100g)	Medium : 5 - 30; High : > 30	26	Medium	49	High	34	High	50	High
pH	Good : 5.0 - 6.5 Fair : 4.0 - 5.0 or 6.5 - 7.5 Poor : 3.5 - 4.0 or 7.5 - 9.0	6.7	Fair	7.7	Poor	6.7	Fair	7.7	Poor
EC (dS / m)	Good : < 2; Fair : 2 - 4	0.39	Good	0.78	Good	0.51	Good	0.72	Good
Texture	Good : FSL, VFSL, L, SiL, SL Fair : CL, SCL, SiCL Poor : LS, SiC, C, HC, S	Clay	Poor	Sandy loam	Good	Clay	Poor	Sandy loam	Good
C:N ratio	25:1	25.88	Above threshold	20.66	Below threshold	22.44	Below threshold	20.51	Below threshold
BS (%)	100	112	Above threshold	120	Above threshold	109	Above threshold	115	Above threshold
ESP (%)	15	0.3	Below threshold	0.0	Below threshold	0.2	Below threshold	0.0	Below threshold
BD (g / cm^3)	1.6 for loam and clay loam 1.49 for > 35 % clay	1.30	Below threshold	0.49	Below threshold	1.04	Below threshold	0.61	Below threshold
PR (MPa)	2	4.6	Above threshold	4.3	Above threshold	4.5	Above threshold	4.5	Above threshold

Table 3.68. Lower layer soil quality at bare and vegetated patches on peat mineral soil mix at MLSB thirteen years after reclamation.

		Bare				Vegetated			
		Cell 18		Cell 16		Cell 18		Cell 16	
Parameter	Criteria or threshold	Mean	Rating	Mean	Rating	Mean	Rating	Mean	Rating
TOC (%)	Good : > 2 Fair : 1 - 2	1.28	Fair	1.40	Fair	1.93	Fair	1.45	Fair
CEC (meg / 100g)	Medium : 5 - 30 High : > 30	13	Medium	13	Medium	15	Medium	12	Medium
pH	Good : 5.0 - 7.0 Fair : 4.0 - 5.0 or 7.0 - 8.0 Poor : 3.5 - 4.5 or 8.0 - 9.0	6.9	Good	7.5	Fair	7.1	Fair	7.5	Fair
EC (dS / m)	Good : < 3 Fair : 3 - 5	1.23	Good	2.58	Good	1.07	Good	2.31	Good
Texture	Good : FSL, VFSL, L, SiL, SL Fair : CL, SiC, SiCL Poor : S, LS, S, C, HC	Sandy clay loam	N/A	Clay	Poor	Sandy clay loam	N/A	Clay loam	Poor
C:N ratio	25:1	43.76	Above threshold	74.50	Above threshold	41.14	Above threshold	46.88	Above threshold
BS (%)	100	152	Above threshold	300	Above threshold	186	Above threshold	285	Above threshold
ESP (%)	15	0.8	Below threshold	0.0	Below threshold	0.6	Below threshold	1.5	Below threshold

Subsurface (lower lift ratings were used for lower layer parameters except in the case of TOC.

CHAPTER IV. SUMMARY, APPLICATIONS AND FUTURE RESEARCH

1. RESEARCH SUMMARY

1.1 Plant Community Development

At four 4 to 13 year old reclaimed sites there were significant differences between LFH mineral soil mix and peat mineral soil mix in species composition and the assemblage of growth forms and dominant species. LFH mineral soil mix had significantly greater woody plant density, species richness, native species richness, total cover, native species cover while peat mineral soil mix had significantly greater non-native species cover. Not all sites had significant differences in all of these parameters over time but there were enough significant differences to show that LFH mineral soil mix was a better cover soil than peat mineral soil mix to support development of biodiverse, native plant communities. LFH mineral soil mix consistently supported more desirable plant communities than peat mineral soil mix under a variety of treatment configurations including different donor materials from sites with different vegetation types, different substrate types, and different salvage and placement depths.

1.2 Examination Of Bare Ground

At 3 reclaimed sites, patches with low vegetation establishment and growth were observed within large areas of dense, diverse vegetation on both LFH mineral soil mix and peat mineral soil mix cover soils. At the 8 year old site, where bare patches were most distinct, there were significant differences in soil chemical and physical properties between bare and vegetated areas. On both cover soils, bare patches had significantly lower cover soil depths, fertility levels and water holding capacities. On peat mineral soil mix, bare patches had higher pH and shallower depths to compacted layers. There were no significant differences in salinity or sodicity levels. Significant differences in organic matter, total organic carbon, total nitrogen and pH over time were found for both patch types. Correlation analysis showed patch type and cover soil specific relationships between vegetation and soil properties. Vegetation characteristics at bare patches differed across cover soils and sites but in most cases non-native cover was greater and shrub cover was lower at bare patches relative to vegetated patches.

2. APPLICATIONS FOR RECLAMATION

2.1 Plant Community Development

LFH mineral soil mix is the preferred cover soil for fine and coarse textured reclamation substrates to promote native plant community development in the long term and should be used whenever possible in reclamation. At the 7 year old site, which had a fine textured substrate, the 10 cm application of LFH mineral soil mix provided the same benefits as the 20 cm application in species composition and richness, woody plant growth and vegetation production. At the 5 year old site, no one combination of application depth, substrate and LFH donor material was clearly most successful. However, the least effective treatment was 10 cm of LFH mineral soil mix from a *Pinus banksiana* and *Populus tremuloides* mixedwood forest on the sand substrate. On fine textured substrates a 10 cm application of LFH mineral soil mix is recommended to most effectively use this limited resource. With coarse textured substrates a 20 cm application would be the prudent option.

2.2 Examination Of Bare Ground

Cover soil spreading operations that result in patches without cover can lead to sparse vegetation on patches even after 8 years. Lack of cover soil creates sub-optimal conditions especially for plant growth requirements. This confirms that cover soil is critical for vegetation establishment and growth on reclaimed sites.

In light of these findings, the question is whether cover soil application processes can be improved to optimize cover soil uniformity. Frozen materials made smooth application of cover soil materials more difficult at W1 dump (Mackenzie 2006, Mackenzie and Naeth 2010), but it is likely impossible to avoid handling and spreading frozen materials given the northerly location of oil sands mining.

Perhaps the more important questions are whether changes to application procedures are necessary, and whether bare patches pose a threat to reclamation success. A higher proportion of non-native species cover was found at bare patches than at vegetated patches. These species could expand into the surrounding native vegetation. Native vegetation, especially those species with wide habitat tolerances, might also colonize those patches and compete with non-native and weedy species. Areas with shallower cover soil may actually increase the overall diversity of the reclaimed site by creating an alternative niche for species that otherwise would not be present. Given the relatively small size of bare patches and age of reclaimed sites, the more appropriate first step is likely continued monitoring of bare patches rather than corrective measures. Replacing cover soil at bare areas on previously reclaimed sites, especially with machinery, would be time consuming, expensive and destructive. Continued monitoring would allow us to learn when and how vegetation establishes on areas without cover soil when they are surrounded by diverse vegetation. The most effective method would be to conduct annual site assessments and to carry out vegetation assessments of bare areas periodically as was done here to determine changes over time. Non-native species and weeds in particular should be monitored and if populations grow too large, management actions should be taken, particularly to eradicate any aggressive weedy species.

The discovery of areas without cover soil where vegetation has failed to establish suggests a need to question established cover soil placement methods to improve future reclamation success, especially if continued monitoring shows that bare areas are the cause of weed problems or other deficiencies in revegetation success. Perhaps frozen lumps of peat mineral soil mix and LFH mineral soil mix, which can be difficult to spread uniformly in the reclaimed landscape, can be dealt with by optimizing the season of spreading or by implementing a delay between dumping and spreading to allow the material to thaw. However, there are other factors at play when considering these types of changes. There are many good reasons for conducting reclamation activities in the winter and the concept of leaving cover soil rough on the surface is considered to be a best management practice to create microsites for improved germination of in situ propagules and to control erosion (Alberta Environment and Water 2012). The consequences of uneven cover soil placement that results in areas without any cover soil, which potentially carries a risk of revegetation failure, needs to be weighed appropriately against the many other factors that influence operational timing of activities.

3. STUDY LIMITATIONS

The results from this study are specific to the sites that were studied and to the weather conditions they were subjected to between the time of establishment and final site assessments. Treatment configurations other than those studied including, but not limited to, different salvage and application depths, different donor soils and different receiver site substrates may behave differently than those studied here. Different management activities than those applied to the four research sites including, but not limited to, different fertilizer regimes, different planting prescriptions and different weed management strategies could also yield different results.

These differences limit the conclusions drawn from this study. The four sites, although all reclaimed with the two same cover soils, differed in many other ways which prevented statistical analysis of data from all of the sites combined. Meta-analysis was used as a way of detecting overall trends, but more detailed treatment comparisons could have been detected through ANOVAs had that been possible.

The analysis of changes in vegetation parameters through time was complicated by differences in assessment methods used by different assessors. Differences in the number and size of quadrats were especially problematic for assessment of changes in species richness over time. The ability of statistical tests to detect differences between cover soil treatments in the final year of assessment was likely reduced by low subsample sizes, which led to reduced accuracy of parameter estimates and an increased likelihood of a non-significant result.

4. RECOMMENDATIONS FOR FUTURE RESEARCH

- Continue monitoring the research sites to determine if effects of LFH mineral soil mix on native plant community development persist after 20 or 30 years. Unfortunately continued monitoring of current sites will be confounded by the proximity of cover soil treatments meaning plant species that establish can easily disperse onto nearby treatments.

- Set up large scale trials with experimental units that are several hectares in size to prevent confounding of long term vegetation results by species moving from one treatment to another.
- Investigate dispersal dynamics from adjacent undisturbed forests onto reclaimed sites to understand what species or types of species recolonize reclaimed areas and in what quantities; measure changes in dispersal type over time. This will help direct what species to prioritize in planting and seeding initiatives.
- Examine if species establishing on reclaimed sites are from seeds or propagules present in the cover soil or if they are from outside sources utilizing seed traps and seed bank sampling.
- More detailed accounting of where seed losses occur in the salvaging, stockpiling and placement processes as in a study in Australia's bauxite mining region by Koch et al. (1996). They were able to follow the topsoil from one forest as it went through the reclamation process.
- Determine optimal time of salvaging LFH mineral soil mix from a propagule perspective as in work by Ward et al. (1997) in Australia's bauxite mining region. Develop an understanding of when (what season) the largest amount of seeds are present in undisturbed soil seed banks and what kinds of species are present in what seasons.
- Study effects of planting trees at sites reclaimed using LFH mineral soil mix. LFH mineral soil mix alone does not provide enough trees making this a necessary reclamation prescription, but it is important to understand how well the trees survive with increased competition from understory species originating from LFH mineral soil mix.

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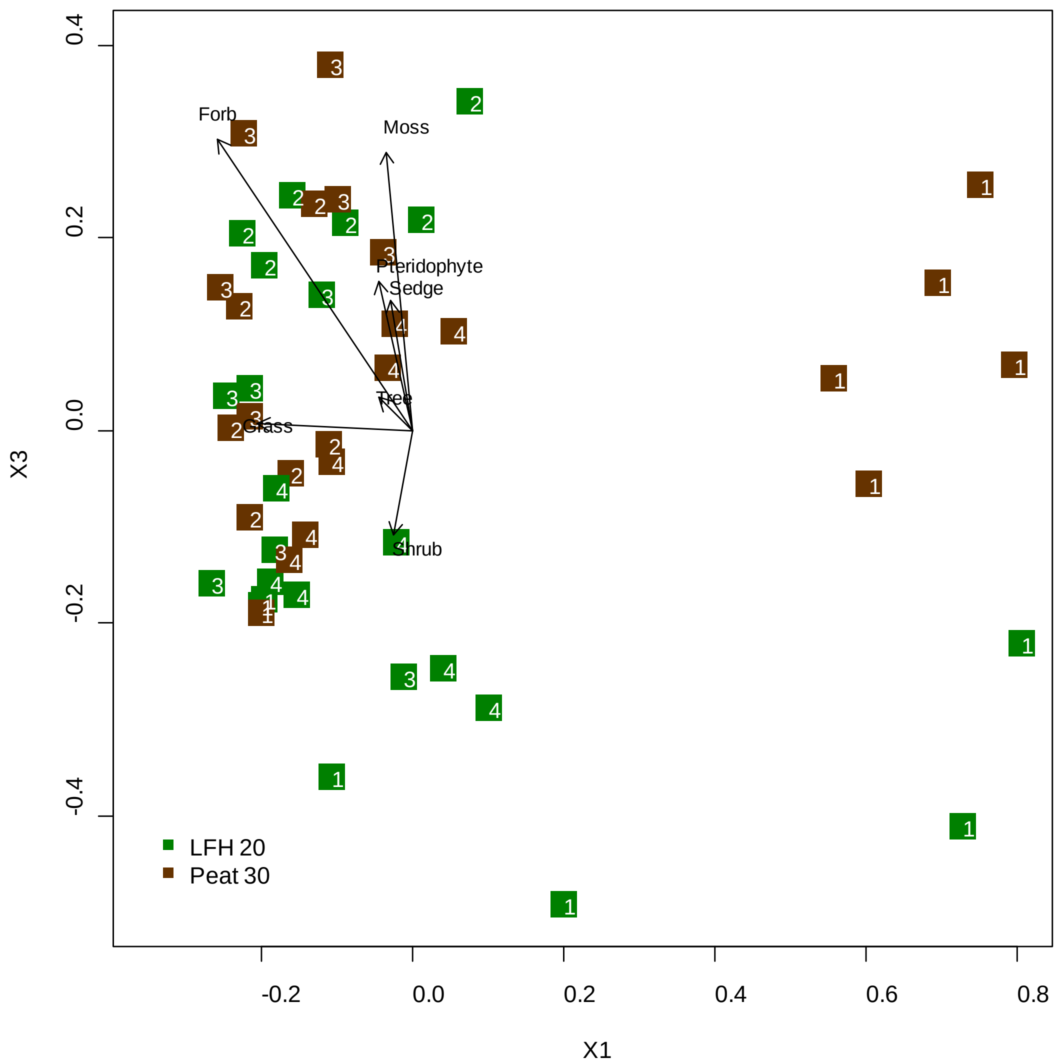

Figure A.1. NMDS ordination (X1 vs X3) of species groups in years 1, 2, 3 and 4 after reclamation at SE dump.

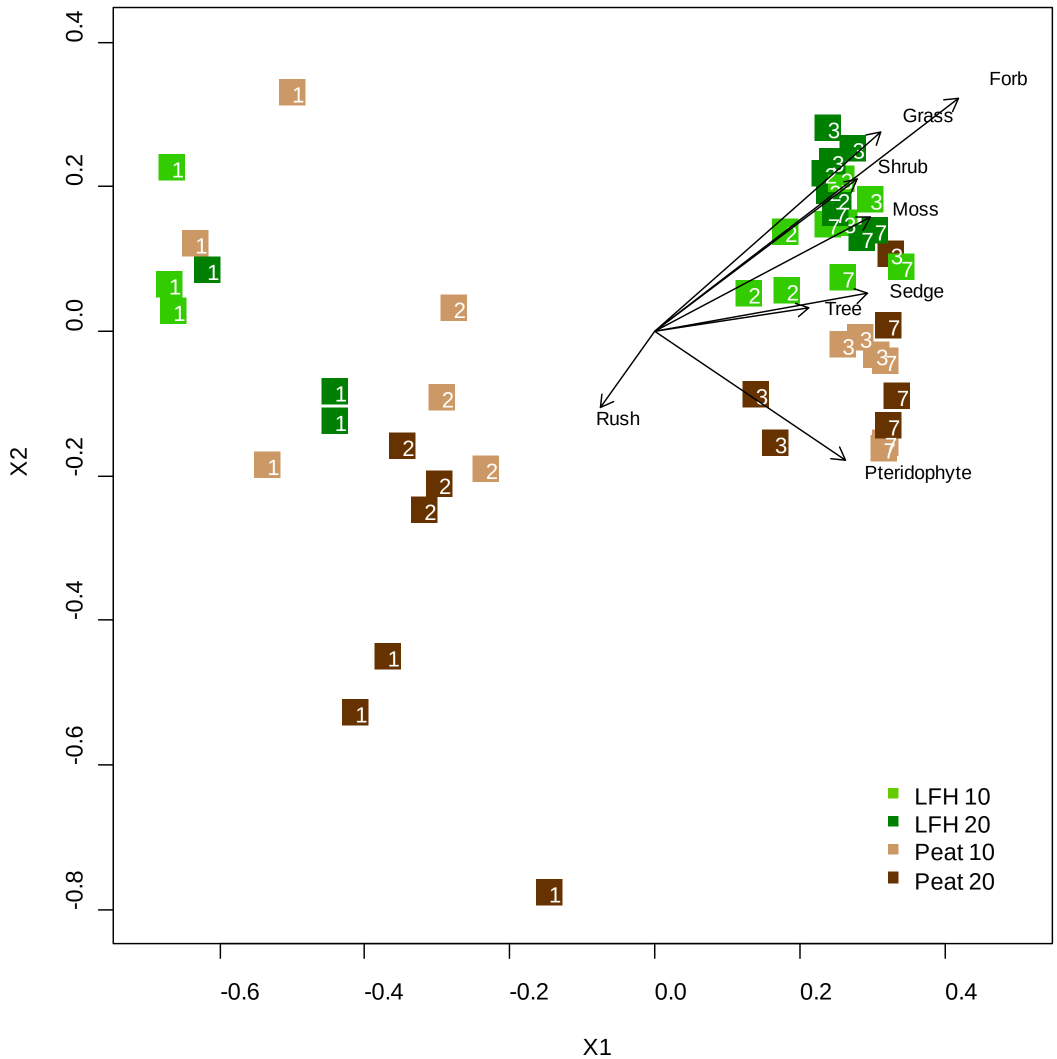

Figure A.2. NMDS ordination (X1 vs X2) of species groups in years 1, 2, 3 and 7 after reclamation at W1 dump.

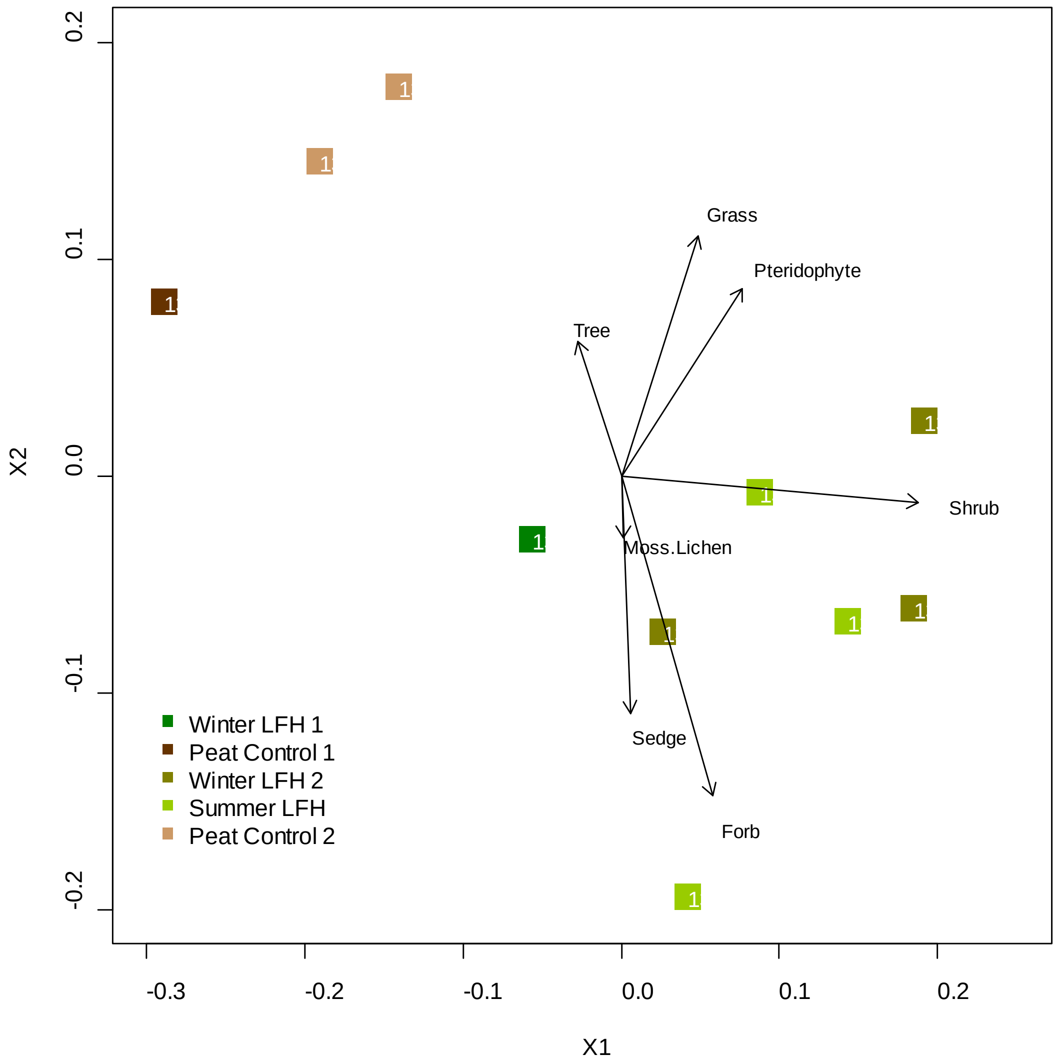

Figure A.3. NMDS ordination (X1 vs X2) of species groups in year 13 after reclamation at MLSB.

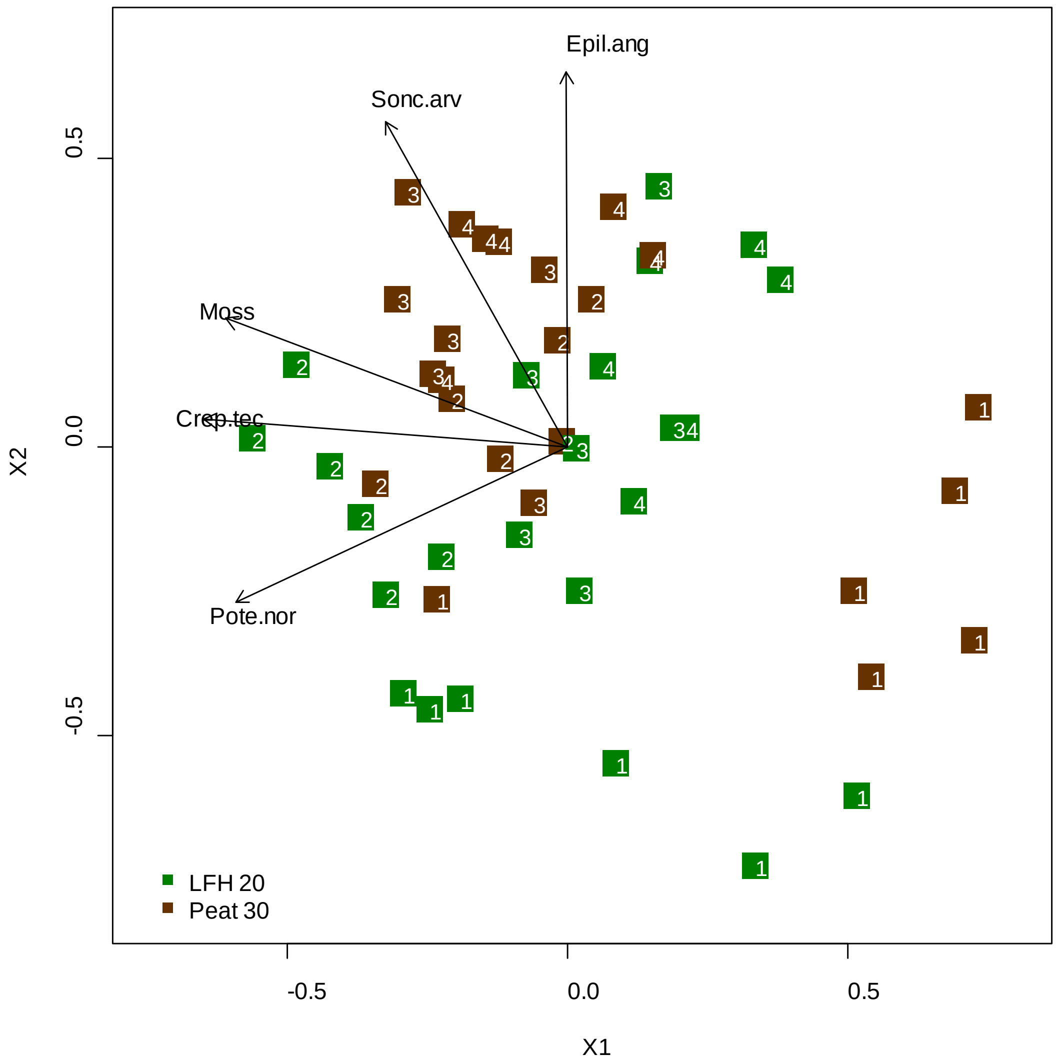

Figure A.4. NMDS ordination (X1 vs X2) of species composition in years 1, 2, 3 and 4 after reclamation at SE dump. Vectors show species that are highly correlated with data (r > 0.5); less correlated vectors are not shown.

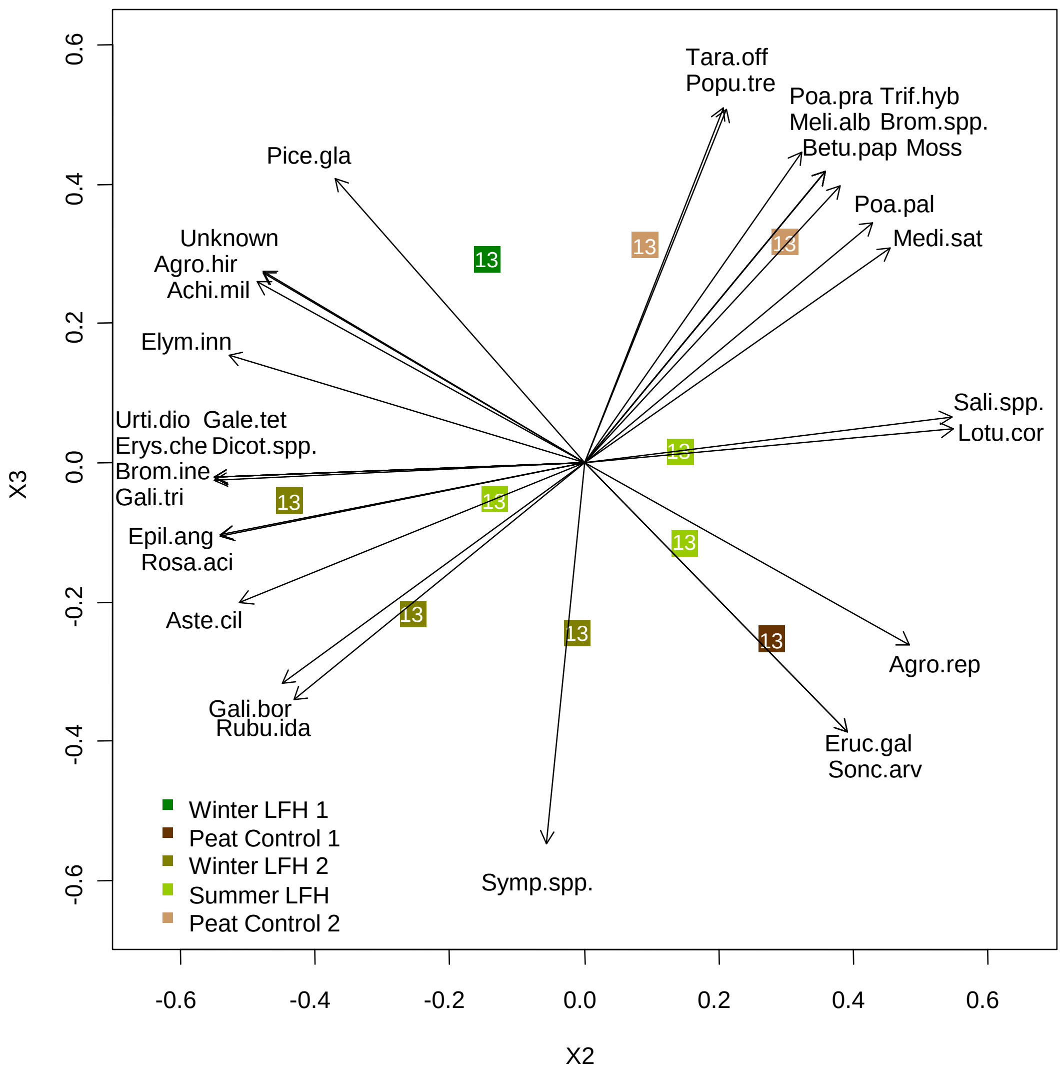

Figure A.5. NMDS ordination (X2 vs X3) of species composition in year 13 after reclamation at MLSB. Vectors show species that are highly correlated with data (r > 0.5); less correlated vectors are not shown.

Table A.1. Slope and aspect for SE dump plots.

Cover soil	Replicate	Compass direction (degrees)	Aspect	Slope %
LFH mineral soil mix	1	116	ESE	8
	2	119	ESE	6
	3	111	ESE	3
	4	118	ESE	6
	5	111	ESE	10
	6	111	ESE	10
Peat mineral soil mix	1	107	ESE	6
	2	114	ESE	6
	3	114	ESE	3
	4	114	ESE	7
	5	112	ESE	8
	6	111	ESE	9

Table A.2. Slope and aspect for W1 dump.

Cover soil	Application depth (cm)	Rep	Aspect		Slope %					Slope length (m)				
			Direction	Degrees	Upper slope	Upper bench	Middle slope	Lower bench	Lower slope	Upper slope	Upper bench	Middle slope	Lower bench	Lower slope
Peat	20	1	SSE	160	11	3.5	9	3	10	21.1	28.2	26.4	37.5	37
LFH	20	1	SE	130	13	3	14	2.5	9	22.8	36	13	39	37
LFH	10	1	SE	131	13	2	11	3	11	27	26.7	12.3	30.7	35
Peat	10	1	SE	140	14	2	16	3	10	19.5	31.5	23.4	46	34
LFH	10	2	SE	133	10	2	12	4.5	6	22.1	22.5	32.6	38.5	33.5
Peat	10	2	SE	141	12	4	8	0	8	16.8	28	37	28	40
Peat	20	2	SE	136	8	1	13.5	3	9	33.9	10.5	36.5	34.1	37.5
Peat	20	3	SE	133	10	3	7	2	8	22.1	23.8	45.5	21.5	35.6
LFH	10	3	SE	130	9	6	12	2	9	21	21.4	46	28.5	31.6
Peat	10	3	SE	128	11	5	10	4	6.5	22.5	19	42.6	19.3	45
LFH	20	2	SE	124	11	4	11	5	11.5	16.5	27.1	36	33.5	32
LFH	20	3	SE	130	11.5	4	11	2	6	26	21.4	37	23	38.8

Peat refers to peat mineral soil mix.
LFH refers to LFH mineral soil mix.

Table A.3. Slope and aspect for MLSB plots.

Site	Cover soil	Replicate	Slope %	Aspect
Cell 18	Winter LFH mineral soil mix	1	13	NNE
	Winter LFH mineral soil mix	2	13	N
	Winter LFH mineral soil mix	3	11	N
	Summer LFH mineral soil mix	1	11	N
	Summer LFH mineral soil mix	2	12	N
	Summer LFH mineral soil mix	3	11	N
	Peat mineral soil mix	1	14	N
	Peat mineral soil mix	2	8	N
Cell 16	LFH mineral soil mix	1	1	N/A
	Peat mineral soil mix	1	1	N/A

Table A.4. List of recorded species at SE dump, W1 dump, Aurora and MLSB sites and their characteristics.

Species	Family	Common name	Origin	Life form
Grasses				
Agroelymus hirtiflorus (A.S. Hitchc.) Bowden	Gramineae	-	Native	Perennial
Agropyron pectiniforme R. & S.	Gramineae	Crested wheat grass	Non-native	Perennial
Agropyron repens (L.) Beauv.	Gramineae	Quack grass	Non-native	Perennial
Agropyron trachycaulum (Link) Malte	Gramineae	Slender wheat grass	Native	Perennial
Agrostis scabra Willd.	Gramineae	Tickle grass	Native	Perennial
Agrostis stolonifera L.	Gramineae	Red top	Non-native	Perennial
Alopecurus aequalis Sobol.	Gramineae	Water foxtail	Native	Perennial
Beckmannia syzigachne (Steud.) Fern.	Gramineae	Slough grass	Native	Annual
Bromus ciliatus L.	Gramineae	Fringed brome	Native	Perennial
Bromus inermis Leyss. ssp. *inermis* Leyss	Gramineae	Smooth brome	Non-native	Perennial
Calamagrostis canadensis (Michx.) Beauv.	Gramineae	Marsh reed grass	Native	Perennial
Cinna latifolia (Trev.) Griseb.	Gramineae	Drooping wood reed	Native	Perennial
Dactylis glomerata L.	Gramineae	Orchard grass	Non-native	Perennial
Deschampsia cespitosa (L.) Beauv.	Gramineae	Tufted hair grass	Native	Perennial
Elymus innovatus Beal	Gramineae	Hairy wild rye	Native	Perennial
Festuca ovina L.	Gramineae	Sheep fescue	Non-native	Perennial
Festuca saximontana Rydb.	Gramineae	Rocky mountain fescue	Native	Perennial
Glyceria grandis S. Wats *ex* A. Gray	Gramineae	Tall manna grass	Native	Perennial
Hordeum jubatum L.	Gramineae	Foxtail barley	Native	Perennial
Koeleria macrantha (Ledeb.) J.A. Schultes f.	Gramineae	June grass	Native	Perennial

Scientific names and authorities as per Moss (1994).
Information on growth form, origin, and life history strategy was found in Moss (1994), Tannas (2003a, 2003b, 2003c) and Johnson et al. (1995).

Table A.4. List of recorded species at the SE dump, W1 dump, Aurora and MLSB sites and their characteristics (continued).

Species	Family	Common name	Origin	Life form
Oryzopsis pungens (Torr.) A.S. Hitchc.	Gramineae	Northern rice grass	Native	Perennial
Phleum pratense L.	Gramineae	Timothy	Non-native	Perennial
Poa palustris L.	Gramineae	Fowl blue grass	Native	Perennial
Poa pratensis L.	Gramineae	Kentucky blue grass	Non-native[1]	Perennial
Poa sp. L.	Gramineae	Bluegrass	-	-
Schizachne purpurascens (Torr.) Swallen ssp. *purpurascens* (T.) S.	Gramineae	False melic	Native	Perennial
Sedges				
Carex aenea Fern.	Cyperaceae	Silvery flowered sedge	Native	Perennial
Carex aquatilis Wahlenb.	Cyperaceae	Water sedge	Native	Perennial
Carex aurea Nutt.	Cyperaceae	Golden sedge	Native	Perennial
Carex chordorrhiza L.f.	Cyperaceae	Prostrate sedge	Native	Perennial
Carex deflexa Hornem.	Cyperaceae	Bent sedge	Native	Perennial
Carex disperma Dewey	Cyperaceae	Two seeded sedge	Native	Perennial
Carex norvegica Retz.	Cyperaceae	Norway sedge	Native	Perennial
Carex siccata Dewey	Cyperaceae	Hay sedge	Native	Perennial
Carex sp. L.	Cyperaceae	Sedge	-	Perennial
Scirpus caespitosus L.	Cyperaceae	Tufted bulrush	Native	Perennial
Luzula parviflora (Ehrh.) Desv.	Juncacaea	Small flowered wood rush	Native	Perennial
Forbs				
Achillea millefolium L.	Asteraceae	Common yarrow	Native	Perennial

[1] Some subspecies are native and others are non-native.
Scientific names and authorities as per Moss (1994).
Information on growth form, origin, and life history strategy was found in Moss (1994), Tannas (2003a, 2003b, 2003c) and Johnson et al. (1995).

Table A.4. List of recorded species at the SE dump, W1 dump, Aurora and MLSB sites and their characteristics (continued).

Species	Family	Common name	Origin	Life form
Achillea sibirica Ledeb.	Asteraceae	Siberian yarrow	Native	Perennial
Actaea rubra (Ait.) Willd.	Ranunculaceae	Red and White Baneberry	Native	Perennial
Anemone multifida Poir.	Ranunculaceae	Cut-leaved anemone	Native	Perennial
Apocynum androsaemifolium L.	Apocynaceae	Spreading dogbane	Native	Perennial
Aralia nudicaulis L.	Araliaceae	Wild sarsaparilla	Native	Perennial
Arnica cordifolia Hook.	Asteraceae	Heart leaved arnica	Native	Perennial
Arnica chamissonis Less.	Asteraceae	Leafy arnica	Native	Perennial
Artemisia biennis Willd.	Asteraceae	Biennial sagewort	Native	Annual, biennial
Aster borealis (T.&G.) Prov.	Asteraceae	Marsh aster; rush aster	Native	Perennial
Aster ciliolatus Lindl.	Asteraceae	Lindley's aster	Native	Perennial
Aster conspicuus Lindl.	Asteraceae	Showy aster	Native	Perennial
Aster puniceus L.	Asteraceae	Purple stemmed aster	Native	Perennial
Astragalus americanus (Hook.) M.E. Jones	Fabaceae	American milk vetch	Native	Perennial
Astragalus canadensis L.	Fabaceae	Canadian milk vetch	Native	Perennial
Astragalus dasyglottis Fisch. *ex* DC.	Fabaceae	Purple milk vetch	Native	Perennial
Astragalus spp. L.	Fabaceae	Milk vetch	-	Perennial
Atriplex subspicata (Nutt.) Rydb.	Chenopodiaceae	Salt rush	Native	Annual
Campanula rotundifolia L.	Campanulaceae	Bluebell, harebell	Native	Perennial
Cerastium arvense L.	Caryophyllaceae	Field chickweed	Native	Perennial
Cerastium vulgatum L.	Caryophyllaceae	Mouse eared chickweed	Non-native	Perennial
Cerastium nutans Raf.	Caryophyllaceae	Long stalked chickweed	Native	Annual

Scientific names and authorities as per Moss (1994).
Information on growth form, origin, and life history strategy was found in Moss (1994), Tannas (2003a, 2003b, 2003c) and Johnson et al. (1995).

Table A.4. List of recorded species at the SE dump, W1 dump, Aurora and MLSB sites and their characteristics (continued).

Species	Family	Common name	Origin	Life form
Chenopodium album L.	Chenopodiaceae	Lamb's quarters	Non-native	Annual
Chenopodium capitatum (L.) Aschers.	Chenopodiaceae	Strawberry blite	Native	Annual
Circaea alpina L.	Onagraceae	Enchanter's nightshade	Native	Perennial
Cirsium arvense (L.) Scop.	Asteraceae	Canada thistle	Non-native	Perennial
Comandra umbellatum (L.) Nutt.	Santalaceae	Bastard toad flax	Native	Perennial
Cornus canadensis L.	Cornacaea	Bunch berry	Native	Perennial
Corydalis aurea Willd.	Fumariaceae	Golden corydalis	Native	Biennial
Corydalis sempervirens (L.) Pers.	Fumariaceae	Pink corydalis	Native	Biennial
Crepis tectorum L.	Asteraceae	Annual hawks beard	Non-native	Annual
Descurainia sophia (L.) Webb	Cruciferae	Flixweed	Non-native	Annual, biennial
Dracocephalum parviflorum Nutt.	Labiatae	American dragon head	Native	Annual, biennial
Epilobium angustifolium L. ssp. *angustifolium* L.	Onagraceae	Fireweed	Native	Perennial
Epilobium ciliatum Raf.	Onagraceae	Fringed willow herb	Native	Perennial
Erigeron canadensis L.	Asteraceae	Horseweed	Native	Annual
Erigeron philadelphicus L.	Asteraceae	Philadelphia fleabane	Native	Biennial, perennial
Erucastrum gallicum (Willd.) Schultz	Cruciferae	Dog mustard	Non-native	Annual
Erysimum cheiranthoides L.	Cruciferae	Wormseed mustard	Native[1]	Annual
Fragaria virginiana Duchesne ssp. *glauca* (S.Wats.) Staudt.	Rosaceae	Wild strawberry	Native	Perennial
Galeopsis tetrahit L.	Labiatae	Hemp nettle	Non-native	Annual
Galium boreale L.	Rubiacese	Northern bedstraw	Native	Perennial

[1] Some subspecies are native and others are non-native.
Scientific names and authorities as per Moss (1994).
Information on growth form, origin, and life history strategy was found in Moss (1994), Tannas (2003a, 2003b, 2003c) and Johnson et al. (1995).

Table A.4. List of recorded species at the SE dump, W1 dump, Aurora and MLSB sites and their characteristics (continued).

Species	Family	Common name	Origin	Life form
Galium triflorum Michx.	Rubiacese	Sweet scented bedstraw	Native	Perennial
Galium trifidum L. ssp. *trifidum*	Rubiacese	Small bedstraw	Native	Perennial
Gentianella amarella (L.) Borner ssp. *acuta* (Michx.) Gillett	Gentianaceae	Northern gentian	Native	Annual, biennial
Geranium bicknellii Britt.	Geraniaceae	Bicknell's cranesbill	Native	Annual, biennial
Geum aleppicum Jacq.	Rosaceae	Yellow avens	Native	Perennial
Geum rivale L.	Rosaceae	Purple avens	Native	Perennial
Hieracium umbellatum L.	Asteraceae	Narrow leaved hawk weed	Native	Perennial
Kochia scoparium (L.) Schrad.	Chenopodiaceae	Kochia	Non-native	Annual
Lactuca serriola L.	Asteraceae	Prickly lettuce	Non-native	Annual, biennial
Lathyrus ochroleucus Hook.	Fabaceae	Cream pea	Native	Perennial
Lathyrus venosus Muhl.	Fabaceae	Veiny pea	Native	Perennial
Lathyrus sp. L.	Fabaceae	Pea vine	Native	Perennial
Lepidium densiflorum Schrad. var. *densiflorum*	Cruciferae	Common pepper grass	Native	Annual
Lilium philadelphicum L. var. *andinum* (Nutt.) Ker	Liliaceae	Western wood lily	Native	Perennial
Linnaea borealis L. ssp. *americanum* (Forbes) Hult.	Caprifoliaceae	Twin flower	Native	Perennial
Lotus corniculatus L.	Fabaceae	Bird's foot trefoil	Non-native	Perennial
Maianthemum canadense Desf.	Liliaceae	Wild lily of the valley	Native	Perennial
Medicago sativa L.	Fabaceae	Alfalfa	Non-native	Perennial
Medicago sp. L.	Fabaceae	Medick	Non-native	Annual, perennial
Melilotus alba Desr.	Fabaceae	White sweet clover	Non-native	Annual, biennial

Scientific names and authorities as per Moss (1994).
Information on growth form, origin, and life history strategy was found in Moss (1994), Tannas (2003a, 2003b, 2003c) and Johnson et al. (1995).

Table A.4. List of recorded species at the SE dump, W1 dump, Aurora and MLSB sites and their characteristics (continued).

Species	Family	Common name	Origin	Life form
Melilotus officinalis (L.) Lam.	Fabaceae	Yellow sweet clover	Non-native	Annual, biennial
Mertensia paniculata (Ait.) G. Don var. *paniculata*	Boraginaceae	Tall mertensia	Native	Perennial
Mitella nuda L.	Saxifragaceae	Bishop's-cap	Native	Perennial
Moehringia lateriflora (L.) Fenzl.	Caryophyllaceae	Blunt leaved sandwort	Native	Perennial
Parnassia palustris L.	Parnassiaceae	Grass of Parnassus	Native	Perennial
Petasites palmatus (Ait.) A. Gray	Asteraceae	Palmate leaved coltsfoot	Native	Perennial
Petasites sagittatus (Pursh) A. Gray	Asteraceae	Arrow leaved Coltsfoot	Native	Perennial
Petasites vitifolius Greene	Asteraceae	Vine leaved coltsfoot	Native	Perennial
Plantago major L.	Plantaginaceae	Common plantain	Non-native	Perennial
Polemonium viscosum Nutt.	Polemoniaceae	Skunkweed	Native	Perennial
Polygonum arenastrum Jord. *ex* Bor.	Polygonaceae	Common knotweed	Non-native	Annual, perennial
Polygonum convolvulus L.	Polygonaceae	Wild buckwheat	Non-native	Annual
Polygonum lapathifolium L.	Polygonaceae	Dockleaf smartweed	Native	Annual
Portulaca oleracea L.	Portulacacaea	Purslane	Non-native	Annual
Potentilla norvegica L.	Rosaceae	Rough cinquefoil	Native	Annual, biennial
Potentilla tridentata Ait.	Rosaceae	Three toothed cinquefoil	Native	Perennial
Ranunculus sceleratus L. ssp. *multifidus* (Nutt.) Hult.	Ranunculaceae	Cursed crowfoot	Native	Annual, perennial
Rhinanthus minor L.	Scrophulariaceae	Yellow rattle	Native	Annual
Rorippa palustris (L.) Besser ssp. *palustris*	Cruciferae	Yellow cress	Native	Annual, biennial
Rubus chamaemorus L.	Rosaceae	Cloudberry	Native	Perennial
Rubus pubescens Raf.	Rosaceae	Dewberry	Native	Perennial

Scientific names and authorities as per Moss (1994).
Information on growth form, origin, and life history strategy was found in Moss (1994), Tannas (2003a, 2003b, 2003c) and Johnson et al. (1995).

Table A.4. List of recorded species at the SE dump, W1 dump, Aurora and MLSB sites and their characteristics (continued).

Species	Family	Common name	Origin	Life form
Rumex triangulivalvis (Dans.) Rech. f.	Polygonaceae	Narrow leaved dock	Native	Perennial
Salsola kali L.	Chenopodiaceae	Russian thistle	Non-native	Annual
Silene spp. L.	Caryophyllaceae	Catchfly	-	Annual, perennial
Solidago canadensis L.	Asteraceae	Canada goldenrod	Native	Perennial
Solidago spathulata DC.	Asteraceae	Mountain goldenrod	Native	Perennial
Sonchus arvensis L.	Asteraceae	Perennial sow thistle	Non-native	Perennial
Stellaria calycantha (Ledeb.) Bong.	Caryophyllaceae	Northern stitchwort	Native	Perennial
Stellaria crassifolia Ehrh.	Caryophyllaceae	Fleshy stitchwort	Native	Perennial
Stellaria longifolia Muhl.	Caryophyllaceae	Long leaved chickweed	Native	Perennial
Taraxacum officinale Weber	Asteraceae	Common dandelion	Non-native	Perennial
Thalictrum venulosum Trel.	Ranunculaceae	Veiny meadow rue	Native	Perennial
Thlaspi arvense L.	Cruciferae	Stinkweed	Non-native	Annual
Typha latifolia L.	Typhaceae	Common cattail	Native	Perennial
Trientalis borealis Raf. ssp. *latifolia* (Hook.) Hult.	Primulaceae	Star flower	Native	Perennial
Trifolium hybridum L.	Fabaceae	Alsike clover	Non-native	Perennial
Trifolium pratense L.	Fabaceae	Red clover	Non-native	Biennial, perennial
Tragopogon dubius Scop.	Asteraceae	Goat's beard	Non-native	Biennial
Urtica dioica L.	Cannabinaceae	Common nettle	Native	Perennial
Valeriana dioica L. ssp. *sylvanica* (Rich.) F.G. Mey	Valerinanacaea	Northern valerian	Native	Perennial
Vicia americana Muhl.	Fabaceae	Wild vetch	Native	Perennial
Viola adunca J.E. Smith	Violaceae	Early blue violet	Native	Perennial

Scientific names and authorities as per Moss (1994).
Information on growth form, origin, and life history strategy was found in Moss (1994), Tannas (2003a, 2003b, 2003c) and Johnson et al. (1995).

Table A.4. List of recorded species at the SE dump, W1 dump, Aurora and MLSB sites and their characteristics (continued).

Species	Family	Common name	Origin	Life form
Viola renifolia A. Gray	Violaceae	Kidney leaved violet	Native	Perennial
Pteridophytes				
Equisetum arvense L.	Equisetaceae	Common horsetail	Native	Perennial
Equisetum pratense Ehrh.	Equisetaceae	Meadow horsetail	Native	Perennial
Equisetum scirpoides Michx.	Equisetaceae	Dwarf scouring rush	Native	Perennial
Equisetum sylvaticum L.	Equisetaceae	Woodland horsetail	Native	Perennial
Shrubs				
Alnus crispa (Ait.) Pursh	Betulaceae	Green alder	Native	Perennial
Amelanchier alnifolia Nutt.	Rosaceae	Saskatoon	Native	Perennial
Arctostaphylos uva-ursi (L.) Spreng.	Ericacaea	Common bearberry	Native	Perennial
Betula glandulosa Michx.	Betulaceae	Bog birch	Native	Perennial
Caragana arborescens Lam.	Fabaceae	Common caragana	Non-native	Perennial
Cornus stolonifera Michx.	Cornaceae	Red-osier dogwood	Native	Perennial
Ledum groenlandicum Oeder	Ericacaea	Common labrador tea	Native	Perennial
Lonicera dioica L. var. *glaucescens* (Rydb.) Butters	Caprifoliaceae	Twining honeysuckle	Native	Perennial
Potentilla fruticosa L.	Rosaceae	Shrubby cinquefoil	Native	Perennial
Prunus pensylvanica L.f.	Rosaceae	Pin cherry	Native	Perennial
Prunus virginiana L.	Rosaceae	Choke cherry	Native	Perennial
Ribes americanum Mill	Grossulariaceae	Wild black currant	Native	Perennial
Ribes glandulosum Grauer	Grossulariaceae	Skunk currant	Native	Perennial
Ribes hudsonianum Richards.	Grossulariaceae	Wild black currant	Native	Perennial

Scientific names and authorities as per Moss (1994).
Information on growth form, origin, and life history strategy was found in Moss (1994), Tannas (2003a, 2003b, 2003c) and Johnson et al. (1995).

Table A.4. List of recorded species at the SE dump, W1 dump, Aurora and MLSB sites and their characteristics (continued).

Species	Family	Common name	Origin	Life form
Ribes lacustre (Pers.) Poir.	Grossulariaceae	Bristly black currant	Native	Perennial
Ribes oxyacanthoides L.	Grossulariaceae	Wild gooseberry	Native	Perennial
Ribes triste Pall.	Grossulariaceae	Wild red currant	Native	Perennial
Rosa acicularis Lindl.	Rosaceae	Prickly rose	Native	Perennial
Rubus idaeus L.	Rosaceae	Wild red raspberry	Native	Perennial
Salix exigua Nutt.	Salicaceae	Sand willow	Native	Perennial
Salix myrtillifolia Anderss.	Salicaceae	Myrtle eaved willow	Native	Perennial
Salix sp. L.	Salicaceae	Willow	Native	Perennial
Shepherdia canadensis (L.) Nutt.	Elaeagnaceae	Canada buffalo berry	Native	Perennial
Symphoricarpos albus (L.) Blake	Caprifoliaceae	Snowberry	Native	Perennial
Symphoricarpos occidentalis Hook.	Caprifoliaceae	Buckbrush	Native	Perennial
Symphoricarpos spp. Duhamel	Caprifoliaceae	Snowberry	Native	Perennial
Vaccinium myrtilloides Michx.	Ericacaea	Blueberry	Native	Perennial
Vaccinium vitis-idaea L.	Ericacaea	Bog cranberry	Native	Perennial
Trees				
Betula papyrifera Marsh.	Betulacaea	Paper birch	Native	Perennial
Picea glauca (Moench) Voss	Pinaceae	White spruce	Native	Perennial
Picea mariana (Mill.) BSP.	Pinaceae	Black spruce	Native	Perennial
Pinus banksiana Lamb.	Pinaceae	Jack pine	Native	Perennial
Populus balsamifera L.	Salicaceae	Balsam poplar	Native	Perennial
Populus tremuloides Michx.	Salicaceae	Trembling aspen	Native	Perennial

Scientific names and authorities as per Moss (1994).
Information on growth form, origin, and life history strategy was found in Moss (1994), Tannas (2003a, 2003b, 2003c) and Johnson et al. (1995).

Table A.5. Additional information on dominant species at the SE dump, W1 dump, Aurora and MLSB sites.

Species	Habitat	CSR classification	Successional stage
Achillea millefolium	Natural and disturbed	CR/CSR	Early to late
Agroyron repens	Disturbed	SC/CSR or C/CSR	N/A
Agropyron trachycaulum	Natural and disturbed	C	Early
Agropyron sp.	Natural	Unknown	Unknown
Agrostis scabra	Natural and disturbed	Unknown	Early
Amelanchier alnifolia	Natural	C/SC	Early to late
Aster ciliolatus	Natural	C	Early to late
Aster conspicuous	Natural	C or C/CR	Early to late
Atriplex subspicata	Natural and disturbed	Unknown	Early
Betula papyrifera	Natural	C/SC	Early to late
Bromus inermis	Disturbed	C/SC	-
Bromus sp.	Natural	Unknown	Unknown
Calamagrostis canadensis	Natural	C/CSR	Early
Carex aenea	Natural	Unknown	Early to late
Carex siccata	Natural	Unknown	Early to late
Carex sp.	Natural	Unknown	Early to late
Chenopodium album	Disturbed	R/CR	-
Chenopodium capitatum	Disturbed	R/CR	Early
Corydalis aurea	Natural and disturbed	Unknown	Early
Crepis tectorum	Disturbed	CR	-
Elymus innovatus	Natural	C/CSR	Early to late

Habitat information was obtained from Tannas (2003a, 2003b, 2003c).
CSR classifications were based on collected data when possible; uncollected species were classified using Grime et al. (2007).

Table A.5. Additional information on dominant species at the SE dump, W1 dump, Aurora and MLSB sites (continued).

Species	Habitat	CSR classification	Successional stage
Epilobium angustifolium	Natural and disturbed	C	Early
Equisetum arvense	Natural and disturbed	CR	Early to late
Equisetum sylvaticum	Natural	CSR	Early to late
Erucastrum gallicum	Disturbed	Unknown	-
Erysimum cheiranthoides	Disturbed	R	Early
Fragaria virginiana	Natural and disturbed	C/SC or SC	Early
Galeopsis tetrahit	Disturbed	R/CR	-
Galium borealis	Natural and disturbed	C/CR or CR	Early to late
Galium triflorum	Natural	C/CR	Early to late
Geranium bicknellii	Natural and disturbed	SC	Early
Hordeum jubatum	Natural and disturbed	R/CSR	Early
Koelaria macrantha	Natural	S	Early to late
Lathyrus venosus	Natural	C or C/CR	Early to late
Lotus corniculatus	Disturbed	S/CSR	-
Medicago sativa	Disturbed	C/CSR	-
Melilotus alba	Disturbed	CR	-
Mertensia paniculata	Natural	C/CR	Early to late
Moss sp.	Natural	Unknown	Early to late
Oryzopsis pungens	Natural	Unknown	Early to late
Picea glauca	Natural	Unknown	Early to late
Poa palustris	Natural and disturbed	CSR	Early

Habitat information was obtained from Tannas (2003a, 2003b, 2003c).
CSR classifications were based on collected data when possible; uncollected species were classified using Grime et al. (2007).

Table A.5. Additional information on dominant species at the SE dump, W1 dump, Aurora and MLSB sites (continued).

Species	Habitat	CSR classification	Successional stage
Poa pratensis	Natural and disturbed	CSR	N/A
Populus tremuloides	Natural	C	Early to late
Potentilla norvegica	Natural and disturbed	C/CR	Early
Rosa acicularis	Natural and disturbed	C or C/CR	Early to late
Rubus idaeus	Natural and disturbed	SC	Early
Salix sp.	Natural	C	Early to late
Schizachne purpurascens	Natural	Unknown	Early to late
Sonchus arvensis	Disturbed	CR	N/A
Symphoricarpos sp.	Natural	C/SC	Early to late
Taraxacum officinalis	Disturbed	R/CSR	N/A
Urtica dioica	Natural and disturbed	C	Early
Vaccinium myrtilloides	Natural	SC or C/SC	Early to late
Vicia americana	Natural	C/CR or CR or C	Early to late
Viola adunca	Natural	Unknown	Early

Habitat information was obtained from Tannas (2003a, 2003b, 2003c).
CSR classifications were based on collected data when possible; uncollected species were classified using Grime et al. (2007).

Table A.6. Mean treatment species richness at SE dump in the first four years after reclamation.

Year	Treatment richness		Treatment native richness		Treatment non-native richness	
	LFH mineral soil mix	Peat mineral soil mix	LFH mineral soil mix	Peat mineral soil mix	LFH mineral soil mix	Peat mineral soil mix
2008	42	32	37	26	5	6
2009	54	47	47	39	7	8
2010	51	53	53	43	2	10
2011	65	62	56	52	9	9

Treatment richness was calculated by combining the lists of species from all experimental units and removing duplicates.
2008, 2009 data from Brown (2010), 2011 data from Forsch (unpublished), n = 6.

Table A.7. Mean treatment species richness at Aurora in the first five years after reclamation.

Year	Cover soil	Application depth (cm)	Treatment richness		Treatment native richness		Treatment non-native richness	
			Sand	Peat-sand	Sand	Peat-sand	Sand	Peat-sand
2006	LFH mineral soil mix	10	26	31	25	30	1	1
	LFH mineral soil mix	20	29	30	29	28	0	2
	Peat mineral soil mix	-		13		11		2
2007	LFH mineral soil mix	10	36	36	33	33	3	3
	LFH mineral soil mix	20	39	40	36	37	3	3
	Peat mineral soil mix	-		27		23		4
2008	LFH mineral soil mix	10	36	42	34	39	2	3
	LFH mineral soil mix	20	34	41	32	39	2	2
	Peat mineral soil mix	-		28		23		5
2010	LFH mineral soil mix	10	32	47	31	42	1	5
	LFH mineral soil mix	20	35	42	32	37	3	5
	Peat mineral soil mix	-		36		31		5

Treatment richness was calculated by combining species from all experimental units and removing duplicates, n = 3.
2006, 2007, 2008 data from Mackenzie (2012a).

Table A.8. Mean treatment species richness at W1 dump in the first seven years after reclamation.

Year	Application depth (cm)	Treatment richness: LFH mineral soil mix	Treatment richness: Peat mineral soil mix	Treatment native richness: LFH mineral soil mix	Treatment native richness: Peat mineral soil mix	Treatment non-native richness: LFH mineral soil mix	Treatment non-native richness: Peat mineral soil mix
2004	10	32	14	31	12	1	2
	20	33	13	28	12	5	1
2005	10	51	34	43	30	8	4
	20	58	32	51	28	7	4
2006	10	56	51	51	44	5	7
	20	61	46	54	40	7	6
2010	10	62	61	53	52	9	9
	20	66	53	55	45	11	8

Treatment richness was calculated by combining species from all experimental units and removing duplicates, n = 3.
2004, 2005, 2006 data from Mackenzie (2006), Mackenzie (unpublished).

Table A.9. Mean treatment species richness at MLSB twelve and thirteen years after reclamation.

Year	Site	Cover soil	Application depth (cm)	Application season	Treatment richness	Treatment native richness	Treatment non-native richness
2010	Cell 16	LFH mineral soil mix	18	Winter	51	38	13
		Peat mineral soil mix	18	Unknown	32	19	13
	Cell 18	LFH mineral soil mix	12	Winter	70	55	15
		LFH mineral soil mix	12	Summer	59	46	13
		Peat mineral soil mix	18	Unknown	53	38	15
2011	Cell 16	LFH mineral soil mix	18	Winter	45	33	12
		Peat mineral soil mix	18	Unknown	26	17	9
	Cell 18	LFH mineral soil mix	12	Winter	61	50	11
		LFH mineral soil mix	12	Summer	56	45	11
		Peat mineral soil mix	18	Unknown	51	35	16

Treatment richness was calculated by combining species from all experimental units and removing duplicates.
n = 1 at Cell 16, n = 3 for LFH mineral soil mix at Cell 18, n = 2 for peat mineral soil mix at Cell 18.

APPENDIX B. ADDITIONAL TABLES FROM CHAPTER III

Table B.1. Sampling and slope information for each bare and vegetated pair on two cover soils at the SE dump.

Cover soil	Replicate	Pair no.	Distance between bare and vegetated (m)	Slope position	Slope %	Vegetation assessment	Soil samples	Bulk density sample	Penetration resistance reading
LFH mineral soil mix	4	1	2.1	mid slope	6	+	+	+	-
		2	4.5	mid slope	6	+	+	+	-
	5	1	0.6	mid slope	10	+	+	+	-
		2	8	mid slope	10	+	+	+[1]	-
		3	10.1	mid slope	10	+	+	-	-
	6	1	8.2	mid slope	10	+	+	-	-
		2	4	mid slope	10	+	+	+[1]	-
Peat mineral soil mix	4	1	20.9	mid slope	7	+	+	+[1]	-
		2	7.3	mid slope	7	+	+	+[1]	-
	5	1	8.7	mid slope	8	+	+	+[1]	-
		2	6	mid slope	8	+	+	+	-
		3	2.4	mid slope	8	+	+	+[1]	-
	6	1	4.4	mid slope	9	+	+	+	-
		2	8.9	mid slope	9	+	+	+[1]	-
		3	10.8	mid slope	9	+	+	+[1]	-
		4	5.5	mid slope	9	+	+	-	-
		5	8	mid slope	9	+	+	+	-

[1] At these pairs only one of the paired patches was sampled for bulk density.
Replicates 1, 2 and 3 for both cover soils were not sampled as there was no obvious bare patches on LFH mineral soil mix.

Table B.2. Sampling and slope information for each bare and vegetated pair on 10 cm LFH mineral soil mix at W1 dump.

Replicate	Pair no.	Distance between bare and vegetated (m)	Slope position[1]	Slope %[2]	Vegetation assessment	Soil samples	Bulk density sample	Penetration resistance reading
1	1	2.5	upper slope	13	+	+	+	+
	2	2.4	upper bench / upper slope	-	+	-	-	+
	3	1.9	upper bench	2	+	+	+	+
	4	1.8	middle slope	11	+	+	+	+
	5	2.3	lower bench	3	+	+	+	+
	6	1.5	lower slope	11	+	-	-	+
	7	2.2	lower slope	11	+	+	+	+
2	1	1.2	upper slope	10	+	+	+	+
	2	0.8	upper slope	10	+	-	-	+
	3	2.1	upper bench	2	+	+	+	+
	4	2.1	lower bench	4.5	+	+	+	+
	5	1.7	middle slope	12	+	+	+	+
	6	1.8	lower bench	4.5	+	-	-	+
	7	1	lower slope	6	+	+	+	+
3	1	1	upper slope	9	+	+	+	+
	2	1.3	upper bench	6	+	+	-	+
	3	1.6	upper bench	6	+	+	+	+
	4	1.8	middle slope	12	+	+	+	+
	5	1	lower bench / middle slope	-	+	+	+	+
	6	1.7	lower bench	2	+	+	-	+
	7	1.8	lower slope	9	+	+	+	+

[1] Five slopes in the treatment area are upper slope, upper bench, middle slope, lower bench, lower slope.
[2] Slope % was not available for pairs located in transition zone between slope positions.

Table B.3. Sampling and slope information for each bare and vegetated pair on 20 cm LFH mineral soil mix at W1 dump.

Replicate	Pair no.	Distance between bare and vegetated (m)	Slope position[1]	Slope %[2]	Vegetation assessment	Soil samples	Bulk density sample	Penetration resistance reading
1	1	1.5	lower slope	9	+	+	+	+
	2	1.4	lower slope	9	+	+	+	+
	3	1.2	lower bench	2.5	+	-	-	+
	4	2.8	middle slope / upper bench	-	+	+	+	+
	5	1	upper bench	3	+	+	+	+
	6	3.6	upper bench	3	+	-	-	+
	7	1.3	upper slope	13	+	+	+	+
2	1	2.1	upper slope	11	+	-	-	+
	2	1.1	upper bench	4	+	+	+	+
	3	1.4	upper bench	4	+	+	+	+
	4	0.9	middle slope?	11	+	+	+	+
	5	1.3	lower bench / middle slope	-	+	+	+	+
	6	0.7	lower bench	5	+	-	-	+
	7	1.3	lower slope	11.5	+	+	-	+
3	1	1.7	lower slope	6	+	+	+	+
	2	1.1	edge of lower bench	2	+	+	+	+
	3	1.7	middle slope	11	+	+	+	+
	4	2.6	middle slope	11	+	-	-	+
	5	1.1	middle slope / upper bench	-	+	+	+	+
	6	1	upper bench	4	+	-	-	+
	7	1	upper bench / upper slope	-	+	+	+	+

[1] Five slopes in the treatment area are upper slope, upper bench, middle slope, lower bench, lower slope.
[2] Slope % was not available for pairs located in transition zone between slope positions.

Table B.4. Sampling and slope information for each bare and vegetated pair on 10 cm peat mineral soil mix at W1 dump.

Replicate	Pair no.	Distance between bare and vegetated (m)	Slope position[1]	Slope %[2]	Vegetation assessment	Soil samples	Bulk density sample	Penetration resistance reading
1	1	2.6	lower bench	3	+	+	+	+
	2	3.7	lower bench	3	+	-	-	+
	3	1.9	lower bench	3	+	+	+	+
	4	2.2	lower bench	3	+	+	+	+
	5	0.9	middle slope / upper bench	-	+	+	+	+
	6	1.7	upper bench	2	+	-	-	+
	7	1	upper slope	14	+	+	+	+
2	1	2.1	lower slope	8	+	+	+	+
	2	1.2	middle slope	8	+	-	-	+
	3	1.9	middle slope	8	+	+	+	+
	4	1.6	upper bench	4	+	+	+	+
	5	2.9	upper bench	4	+	+	+	+
	6	1.7	upper slope	12	+	-	-	+
	7	2.7	upper slope	12	+	+	+	+
3	1	2	lower slope	6.5	+	+	+	+
	2	2.4	lower slope	6.5	+	-	-	+
	3	0.9	lower bench	4	+	+	+	+
	4	1.7	middle slope	10	+	+	+	+
	5	2.9	middle slope	10	+	+	+	+
	6	2.1	upper bench	5	+	-	-	+
	7	2	upper slope	11	+	+	+	+

[1] Five slopes in the treatment area are upper slope, upper bench, middle slope, lower bench, lower slope.
[2] Slope % was not available for pairs located in transition zone between slope positions.

Table B.5. Sampling and slope information for each bare and vegetated pair on 20 cm peat mineral soil mix at W1 dump.

Replicate	Pair no.	Distance between bare and vegetated (m)	Slope position[1]	Slope %[2]	Vegetation assessment	Soil samples	Bulk density sample	Penetration resistance reading
1	1	1.1	lower slope	10	+	+	+	+
	2	0.8	lower bench / middle slope	-	+	-	-	+
	3	1.3	middle slope	9	+	+	+	+
	4	1.6	middle slope / upper bench	-	+	+	+	+
	5	1.7	upper bench	3.5	+	+	+	+
	6	1.4	upper bench	3.5	+	+	+	+
	7	1.5	upper slope	11	+	-	-	+
2	1	1.1	upper slope	8	+	+	+	+
	2	0.7	upper slope	8	+	+	+	+
	3	0.8	middle slope	13.5	+	+	-	+
	4	0.7	middle slope	13.5	+	+	-	+
	5	1.9	middle slope	13.5	+	+	-	+
	6	4	lower slope / lower bench	-	+	+	-	+
	7	2	middle slope	13.5	+	+	-	+
3	1	2	lower slope	8	+	+	+	+
	2	1.6	lower bench	2	+	+	-	+
	3	1.3	middle slope	7	+	+	+	+
	4	1.8	middle slope	7	+	+	+	+
	5	0.8	upper bench	3	+	+	+	+
	6	2	upper bench	3	+	+	-	+
	7	1.6	upper slope	10	+	+	+	+

[1] Five slopes in the treatment are are upper slope, upper bench, middle slope, lower bench, lower slope.
[2] Slope % was not available for pairs located in transition zone between slope positions.

Table B.6. Sampling and slope information for each bare and vegetated pair on two cover soils at two sites at MLSB.

Site	Cover soil	Replicate	Pair no.	Distance between bare and vegetated (m)	Slope position	Slope %	Vegetation assessment	Soil samples	Bulk density sample	Penetration resistance reading
Cell 18	LFH mineral soil mix	1	1	0.8	upper slope	13	+	+	-	+
			2	0.6	mid slope	13	+	+	-	+
		3	1	1	mid slope	11	+	+	+	+
			2	1.2	mid slope	11	+	+	-	+
		4	1	0.5	mid slope	11	+	+	+	+
			2	3.3	mid slope	11	+	+	-	+
	Peat mineral soil mix	1	1	1.2	lower slope	14	+	+	-	+
			2	2.6	lower slope	14	+	+	+	+
			3	1.7	lower slope	14	+	+	+	+
		2	1	1.6	lower slope	8	+	+	+	+
			2	1.1	lower slope	8	+	+	+	+
			3	2.4	lower slope	8	+	+	+	+
Cell 16	LFH mineral soil mix	1	1	2.6	no slope	0	+	+	+	+
			2	2.5	no slope	0	+	+	+	+
			3	1.6	no slope	0	+	+	+	+
			4	1.7	no slope	0	+	+	+	+
	Peat mineral soil mix	1	1	1.3	no slope	0	+	+	+	+
			2	1.2	no slope	0	+	+	-	+

Replicates 1 and 3 of LFH mineral soil mix at Cell 18 were winter placed while replicate 4 was summer placed.

Table B.7. Significant correlations with r > 0.5 ($r^2 > 0.25$) between vegetation and upper layer soil properties at bare and vegetated patches on LFH mineral soil mix at W1 dump eight years after reclamation.

Bare	r	p	Vegetated	r	p
BS vs native cover	-0.49165	0.0079	OM vs forb cover	0.50561	0.0061
Bare ground cover vs live vegetation cover	-0.58265	0.0011	TOC vs forb cover	0.50561	0.0061
Bare ground cover vs total cover	-0.59049	0.0009	TC vs forb cover	0.50342	0.0063
Bare ground cover vs native cover	-0.50831	0.0057	C:N vs non-native richness	-0.51371	0.0052
			Water retention at 30 kPa vs forb cover	0.53299	0.0035
			Water retention at 30 kPa vs richness	0.50917	0.0057
			Water retention at 1500 kPa vs forb cover	0.56529	0.0017
			Water holding capacity vs richness	0.51388	0.0052
			Litter cover vs live vegetation cover	-0.66206	0.0001
			Litter cover vs moss cover	-0.67774	<.0001

BS = base saturation. OM = organic matter. TOC = total organic carbon. TC = total carbon. C:N = carbon nitrogen ratio.
There were no significant correlations with r > 0.5 ($r^2 > 0.25$) between vegetation and lower layer soil properties at bare and vegetated patches on LFH mineral soil mix at W1 dump in year 8.

Table B.8. Significant correlations r > 0.5 (r^2 > 0.25) between vegetation and upper layer soil properties at bare and vegetated patches on peat mineral soil mix at W1 dump eight years after reclamation.

Bare	r	p	Vegetated	r	p
Water retention at 10 kPa vs native richness	0.53513	0.0019	Exchangeable Na vs sedge cover	0.52291	0.0025
Litter cover vs total cover	0.5	0.0042	ESP vs sedge cover	0.53842	0.0018
Litter cover vs native cover	0.55092	0.0013	Litter cover vs live vegetation cover	-0.83962	<0.0001
Bare ground cover vs native cover	-0.52451	0.0025	Litter cover vs total cover	-0.54522	0.0015
PR at 5 cm vs richness	-0.55597	0.0004	Litter cover vs shrub cover	-0.50147	0.0041
PR at 5 cm vs native richness	-0.49465	0.0019	Litter cover vs native cover	-0.55493	0.0012
			Bulk density vs richness	-0.53229	0.0062
			Bulk density vs native richness	-0.50209	0.0105
			Volumetric water content vs pteridophyte cover	0.49595	0.0117

PR = penetration resistance. Na = sodium. ESP = exchangeable sodium percentage.

Table B.9. Significant correlations r > 0.5 (r^2 > 0.25) between vegetation and lower layer soil properties at bare and vegetated patches on peat mineral soil mix at W1 dump eight years after reclamation.

Bare	r	p	Vegetated	r	p
N/A	N/A	N/A	C:N vs moss cover	0.51841	0.0161
			Sand vs forb cover	0.54802	0.0017

C:N = carbon nitrogen ratio.

Table B.10. Significant correlations with r > 0.5 ($r^2 > 0.25$) between vegetation and upper layer soil properties at bare and vegetated patches on LFH mineral soil mix at SE dump four years after reclamation.

Bare	r	p	Vegetated	r	p
Exchangeable Na vs total cover	0.80403	0.0293	BS vs shrub cover	-0.78571	0.0362
Exchangeable Na vs forb cover	0.79682	0.0319	pH vs shrub cover	-0.78195	0.0378
Exchangeable Na vs native cover	0.80403	0.0293	pH vs woody plant density	-0.80985	0.0273
ESP vs grass cover	-0.77372	0.0412	Clay vs total cover	-0.85714	0.0137
Sand vs native richness	0.80405	0.0293	Clay vs moss cover	-0.83666	0.0189
Cover soil depth (scenario 1) vs non-native cover	-0.88292	0.0085	Clay vs native cover	-0.85714	0.0137
Cover soil depth (scenario 2) vs non-native cover	-0.84545	0.0166	Water holding capacity vs woody plant density	-0.86075	0.0129
Bare ground cover vs non-native cover	-0.82886	0.0212	Cover soil depth (scenario 1) vs live vegetation	-0.80178	0.0301
			Cover soil depth (scenario 1) vs total cover	0.78571	0.0362
			Cover soil depth (scenario 1) vs moss cover	0.83666	0.0189
			Cover soil depth (scenario 1) vs native cover	0.78571	0.0362
			Cover soil depth (scenario 2) vs live vegetation	-0.80178	0.0301
			Cover soil depth (scenario 2) vs total cover	0.78571	0.0362
			Cover soil depth (scenario 2) vs moss cover	0.83666	0.0189
			Cover soil depth (scenario 2) vs native cover	0.78571	0.0362

Na = sodium. ESP = exchangeable sodium percentage. BS = base saturation.

Table B.11. Significant correlations r > 0.5 (r^2 > 0.25) between vegetation and lower layer soil properties at bare and vegetated patches on LFH mineral soil mix at SE dump four years after reclamation.

Bare	r	p	Vegetated	r	p
Exchangeable Ca vs native richness	-0.81537	0.0254	Exchangeable Ca vs shrub cover	-0.75679	0.0489
Exchangeable Na vs native cover	0.84423	0.0169	Exchangeable Na vs woody plant density	-0.83186	0.0203
BS vs native cover	0.81655	0.025	BS vs shrub cover	-0.79282	0.0334
ESP vs grass cover	-0.77985	0.0386	BS vs native richness	0.82134	0.0235
TEC vs native richness	-0.76923	0.0432	BS vs woody plant density	-0.78358	0.0371
CEC vs native richness	-0.80405	0.0293	ESP vs woody plant density	-0.81409	0.0258
EC vs grass cover	-0.8365	0.019	pH vs non-native richness	-0.85635	0.0139
Sand vs native cover	-0.79282	0.0334	EC vs woody plant density	-0.95431	0.0008
Clay vs non-native cover	0.84688	0.0162	Sand vs native richness	-0.76719	0.0441
			Clay vs shrub cover	-0.92743	0.0026
			Clay vs native richness	0.85749	0.0136

Ca = calcium. Na = sodium. BS = base saturation. ESP = exchangeable sodium percentage. TEC = total exchange capacity. CEC = cation exchange capacity. EC = electrical conductivity.

Table B.12. Significant correlations r > 0.5 ($r^2 > 0.25$) between vegetation and upper layer soil properties at bare and vegetated patches on peat mineral soil mix at SE dump four years after reclamation.

Bare	r	p	Vegetated	r	p
OM vs richness	0.65333	0.0405	pH vs grass cover	-0.6378	0.0473
OM vs native richness	0.69977	0.0243	Clay vs live vegetation cover	-0.69765	0.0249
TIC vs native cover	-0.72783	0.017	Bare ground cover vs grass cover	-0.65947	0.038
TOC vs richness	0.60504	0.0638	Volumetric water content vs woody plant density	0.81969	0.0458
TOC vs native richness	0.66061	0.0376			
TC vs richness	0.71617	0.0198			
TC vs native richness	0.73469	0.0155			
C:N vs non-native cover	0.68158	0.03			
Exchangeable Na vs total cover	-0.76453	0.01			
Exchangeable Na vs forb cover	-0.67684	0.0316			
BS vs total cover	-0.72938	0.0167			
BS vs moss cover	-0.64593	0.0436			
BS vs native cover	-0.68353	0.0293			
ESP vs total cover	-0.81488	0.0041			
ESP vs forb cover	-0.69547	0.0255			
pH vs richness	-0.74218	0.014			
pH vs non-native richness	-0.74049	0.0143			
EC vs total cover	-0.83283	0.0028			
EC vs native cover	-0.76221	0.0104			
Litter cover vs richness	0.67295	0.033			

OM = organic matter. TIC = total inorganic carbon. TOC = total organic carbon. TC = total carbon. C:N = carbon nitrogen ratio. Na = sodium. BS = base saturation. ESP = exchangeable sodium percentage. EC = electrical conductivity.

Table B.12. Significant correlations r > 0.5 (r^2 > 0.25) between vegetation and upper layer soil properties at bare and vegetated patches on peat mineral soil mix at SE dump four years after reclamation (continued).

Bare	r	p	Vegetated	r	p
Litter cover vs native richness	0.72235	0.0183			
Bare ground cover vs live vegetation cover	-0.71843	0.0193			
Bare ground cover vs total cover	-0.69301	0.0263			
Bare ground cover vs richness	-0.72235	0.0183			
Bare ground cover vs native richness	-0.77174	0.0089			

Table B.13. Significant correlations r > 0.5 ($r^2 > 0.25$) between vegetation and lower layer soil properties at bare and vegetated patches on peat mineral soil mix at SE dump four years after reclamation.

Bare	r	p	Vegetated	r	p
OM vs forb cover	0.75	0.0199	C:N vs non-native cover	-0.76473	0.0164
OM vs non-native cover	0.77465	0.0142	Exchangeable Ca vs shrub cover	-0.68333	0.0424
TIC vs non-native cover	0.81816	0.007	Exchangeable Mg vs shrub cover	-0.66667	0.0499
TIC vs richness	0.73208	0.0249	TEC vs shrub cover	-0.68333	0.0424
TIC vs native richness	0.71818	0.0293			
TOC vs forb cover	0.75	0.0199			
TOC vs non-native cover	0.77465	0.0142			
TC vs forb cover	0.75	0.0199			
TC vs non-native cover	0.77465	0.0142			
TN vs forb cover	0.74478	0.0213			
TN vs non-native cover	0.75604	0.0184			
C:N vs forb cover	-0.73333	0.0246			
C:N vs non-native cover	-0.73113	0.0252			
Ca vs forb cover	0.76667	0.0159			
Exchangeable Ca vs non-native cover	0.78335	0.0125			
Exchangeable Ca vs native richness	0.67544	0.0459			
Exchangeable Mg vs forb cover	0.71667	0.0298			
Exchangeable Mg vs non-native cover	0.73983	0.0227			
Exchangeable Na vs non-native cover	0.70959	0.0323			
BS vs live vegetation cover	-0.72425	0.0273			

OM = organic matter. TIC = total inorganic carbon. TOC = total organic carbon. TC = total carbon. C:N = carbon nitrogen ratio. Ca = calcium. Mg = magnesium. Na = sodium. BS = base saturation. ESP = exchangeable sodium percentage. EC = electrical conductivity.

Table B.13. Significant correlations r > 0.5 (r^2 > 0.25) between vegetation and lower layer soil properties at bare and vegetated patches on peat mineral soil mix at SE dump four years after reclamation (continued).

Bare	r	p	Vegetated	r	p
BS vs forb cover	-0.78154	0.0129			
BS vs non-native cover	-0.84262	0.0043			
BS vs richness	-0.68246	0.0428			
BS vs native richness	-0.67251	0.0472			
ESP vs forb cover	-0.74536	0.0212			
ESP vs non-native cover	-0.78823	0.0116			
ESP vs richness	-0.85656	0.0032			
ESP vs native richness	-0.85075	0.0036			
TEC vs forb cover	0.76151	0.0171			
TEC vs non-native cover	0.80411	0.009			
TEC vs native richness	0.69973	0.0359			
CEC vs forb cover	0.74478	0.0213			
CEC vs non-native cover	0.77789	0.0136			
CEC vs richness	0.66676	0.0498			
CEC vs native richness	0.69973	0.0359			
pH vs forb cover	-0.80581	0.0087			
pH vs non-native cover	-0.82354	0.0064			
pH vs richness	-0.77888	0.0134			
pH vs native richness	-0.76896	0.0154			
Sand vs live vegetation cover	-0.86353	0.0027			
Sand vs forb cover	-0.86667	0.0025			

BS = base saturation. ESP = exchangeable sodium percentage. TEC = total exchange capacity. CEC = cation exchange capacity.

Table B.13. Significant correlations $r > 0.5$ ($r^2 > 0.25$) between vegetation and lower layer soil properties at bare and vegetated patches on peat mineral soil mix at SE dump four years after reclamation (continued).

Bare	r	p	Vegetated	r	p
Sand vs non-native cover	-0.86168	0.0028			
Sand vs richness	-0.81721	0.0072			
Sand vs native richness	-0.84643	0.004			
Silt vs forb cover	0.79499	0.0104			
Silt vs non-native cover	0.75604	0.0184			
Clay vs total cover	0.85655	0.0032			

Table B.14. Significant correlations with r > 0.5 (r^2 > 0.25) between vegetation and upper layer soil properties at bare and vegetated patches on LFH mineral soil mix at Cell 18 thirteen years after reclamation.

Bare	r	p	Vegetated	r	p
OM vs live vegetation cover	0.92582	0.008	OM vs forb cover	0.89865	0.0149
OM vs total cover	0.88571	0.0188	OM vs moss cover	0.86577	0.0258
OM vs forb cover	0.89865	0.0149	TIC vs native richness	-0.84853	0.0327
OM vs native cover	0.88571	0.0188	TOC vs forb cover	0.94286	0.0048
TOC vs live vegetation cover	0.92582	0.008	TOC vs moss cover	0.91216	0.0112
TOC vs total cover	0.88571	0.0188	TC vs forb cover	0.89865	0.0149
TOC vs forb cover	0.89865	0.0149	TC vs moss cover	0.86577	0.0258
TOC vs native cover	0.88571	0.0188	C:N vs live vegetation cover	-0.81969	0.0458
TC vs live vegetation cover	0.92582	0.008	C:N vs total cover	-0.82857	0.0416
TC vs total cover	0.88571	0.0188	C:N vs native cover	-0.82857	0.0416
TC vs forb cover	0.89865	0.0149	C:N vs woody plant density	-0.81969	0.0458
TC vs native cover	0.88571	0.0188	Exchangeable Ca vs forb cover	0.94286	0.0048
TN vs total cover	0.84067	0.0361	Exchangeable Ca vs moss cover	0.91216	0.0112
TN vs forb cover	0.88235	0.0199	Exchangeable Na vs shrub cover	-0.92582	0.008
TN vs native cover	0.84067	0.0361	Exchangeable Na vs native richness	-0.9037	0.0135
Exchangeable K vs total cover	0.84067	0.0361	ESP vs shrub cover	-0.92582	0.008
Exchangeable K vs forb cover	0.88235	0.0199	ESP vs native richness	-0.9037	0.0135
Exchangeable K vs native cover	0.84067	0.0361	TEC vs forb cover	0.92763	0.0077
ESP vs live vegetation cover	-0.85	0.0321	TEC vs moss cover	0.92548	0.0081
ESP vs richness	-0.90579	0.0129	CEC vs live vegetation cover	-0.88041	0.0206

OM = organic matter. TIC = total inorganic carbon. TOC = total organic carbon. TC = total carbon. TN = total nitrogen. C:N = carbon nitrogen ratio. Ca = calcium. Na = sodium. K = potassium. ESP = exchangeable sodium percentage. TEC = total exchange capacity. CEC = cation exchange capacity.

Table B.14. Significant correlations with r > 0.5 ($r^2 > 0.25$) between vegetation and upper layer soil properties at bare and vegetated patches on LFH mineral soil mix at Cell 18 thirteen years after reclamation (continued).

Bare	r	p	Vegetated	r	p
ESP vs native richness	-0.9	0.0145	CEC vs forb cover	0.82857	0.0416
Sand vs live vegetation cover	0.92582	0.008	CEC vs moss cover	0.97101	0.0012
Sand vs forb cover	0.81168	0.0499	CEC vs woody plant density	-0.88041	0.0206
Sand vs native richness	0.83324	0.0394	Silt vs live vegetation cover	0.88041	0.0206
Water retention at 30 kPa vs live vegetation	0.92582	0.008	Silt vs woody plant density	0.88041	0.0206
Water retention at 30 kPa vs richness	0.88273	0.0198	Clay vs live vegetation cover	-0.94112	0.0051
Water retention at 1500 kPa vs live vegetation	0.83324	0.0394	Clay vs total cover	-0.82857	0.0416
PR at 5 cm vs total cover	-0.82857	0.0416	Clay vs forb cover	0.82857	0.0416
PR at 5 cm vs forb cover	-0.92763	0.0077	Clay vs moss cover	0.88273	0.0198
PR at 5 cm vs native cover	-0.82857	0.0416	Clay vs native cover	-0.82857	0.0416
PR at 25 cm vs richness	0.85084	0.0317	Clay vs woody plant density	-0.94112	0.0051
PR at 25 cm vs native richness	0.8454	0.034	Water retention at 10 kPa vs forb cover	0.88571	0.0188
			Water retention at 10 kPa vs moss cover	0.91216	0.0112
			Water retention at 10 kPa vs non-native richness	0.92582	0.008
			Water retention at 30 kPa vs non-native richness	0.92582	0.008
			Water retention at 1500 kPa vs forb cover	0.88571	0.0188
			Water retention at 1500 kPa vs moss cover	0.91216	0.0112
			Water holding capacity vs grass cover	-0.84067	0.0361
			Cover soil depth vs shrub cover	0.98561	0.0003
			Depth at maximum PR vs live vegetation cover	-0.83166	0.0401
			Depth at maximum PR vs woody plant density	-0.83166	0.0401

ESP = exchangeable sodium percentage. TEC = total exchange capacity. CEC = cation exchange capacity. PR = penetration resistance.

Table B.15. Significant correlations r > 0.5 (r^2 > 0.25) between vegetation and lower layer soil properties at bare and vegetated patches on LFH mineral soil mix at Cell 18 thirteen years after reclamation.

Bare	r	p	Vegetated	r	p
Sand vs. native richness	0.94868	0.0138	Exchangeable Na vs. richness	-0.89474	0.0403
Silt vs. total cover	-0.9	0.0374	Exchangeable K vs. native richness	-0.91287	0.0305
Silt vs. native cover	-0.9	0.0374	Sand vs. native richness	0.94868	0.0138
Clay vs. live vegetation cover	-0.89443	0.0405	Silt vs. total cover	1	<0.0001
Clay vs. native richness	-0.94868	0.0138	Silt vs. native cover	1	<.0001
			Clay vs. shrub cover	-1	<.0001

Na = sodium. K = potassium.

Table B.16. Significant correlations r > 0.5 (r^2 > 0.25) between vegetation and upper layer soil properties at bare and vegetated patches on peat mineral soil mix at Cell 18 thirteen years after reclamation.

Bare	r	p	Vegetated	r	p
EC vs native cover	-0.84067	0.0361	TIC vs live vegetation cover	-0.85749	0.029
EC vs native richness	-0.89326	0.0165	Ca vs richness	-0.81969	0.0458
Sand vs live vegetation cover	-0.84515	0.0341	Ca vs native richness	-0.88041	0.0206
Clay vs live vegetation cover	0.84515	0.0341	Na vs native cover	0.82808	0.0418
Cover soil depth vs forb cover	-0.89237	0.0168	Na vs non-native cover	-0.82808	0.0418
Litter cover vs native cover	0.94286	0.0048	BS vs live vegetation cover	-0.84515	0.0341
Litter cover vs native richness	0.88041	0.0206	TEC vs richness	-0.81969	0.0458
Bare ground cover vs native cover	-0.94286	0.0048	TEC vs native richness	-0.88041	0.0206
Bare ground vs native richness	-0.88041	0.0206	pH vs live vegetation cover	-0.84515	0.0341
PR at 0 cm vs richness	0.85749	0.029	EC vs native cover	-0.81168	0.0499
Depth at maximum PR vs native cover	-0.92763	0.0077	Sand vs live vegetation cover	-0.84515	0.0341
Depth at maximum PR vs native richness	-0.89326	0.0165	Clay vs native richness	0.88041	0.0206
Volumetric water content vs litter cover	0.9	0.0374	Cover soil depth vs grass cover	0.82857	0.0416
Volumetric water content vs bare ground cover	-0.9	0.0374	Litter cover vs moss cover	-0.9404	0.0052
Volumetric water content vs native cover	0.9	0.0374	Depth at maximum PR vs richness	-0.83166	0.0401
Volumetric water content vs native richness	0.89443	0.0405	Bulk density vs bare ground cover	0.89443	0.0405
			Bulk density vs native cover	-0.9	0.0374

TIC = total inorganic carbon. Ca = calcium. Na = sodium. BS = base saturation. TEC = total exchange capacity. EC = electrical conductivity.

Table B.17. Significant correlations r > 0.5 ($r^2 > 0.25$) between vegetation and lower layer soil properties at bare and vegetated patches on peat mineral soil mix at Cell 18 thirteen years after reclamation.

Bare	r	p	Vegetated	r	p
OM vs richness	0.84515	0.0341	TIC vs live vegetation cover	-0.84515	0.0341
OM vs native richness	0.94112	0.0051	C:N vs native cover	-1	<0.0001
TOC vs richness	0.84515	0.0341	C:N vs non-native cover	1	<0.0001
TOC vs native richness	0.94112	0.0051	Exchangeable Ca vs non-native richness	0.82808	0.0418
TC vs richness	0.84515	0.0341	BS vs live vegetation cover	-0.84515	0.0341
TC vs native richness	0.94112	0.0051	TEC vs non-native richness	0.82808	0.0418
TN vs native cover	0.81168	0.0499	pH vs non-native richness	-0.82808	0.0418
TN vs richness	0.85749	0.029	EC vs live vegetation cover	-0.84515	0.0341
TN vs native richness	0.95486	0.003	EC vs native cover	-0.88571	0.0188
C:N vs native cover	-1	<.0001	EC vs non-native cover	0.88571	0.0188
Exchangeable Mg vs total cover	0.81168	0.0499	Silt vs non-native richness	0.82808	0.0418
Exchangeable Mg vs native cover	0.84067	0.0361			
Exchangeable K vs total cover	0.88273	0.0198			
Exchangeable K vs forb cover	0.95533	0.0029			
BS vs non-native richness	0.87831	0.0213			
CEC vs total cover	0.89865	0.0149			
CEC vs native cover	0.92763	0.0077			
CEC vs richness	0.85749	0.029			
CEC vs native richness	0.83166	0.0401			
Sand vs total cover	-0.81168	0.0499			

OM = organic matter. TIC = total inorganic carbon. TOC = total organic carbon. TC = total carbon. TN = total nitrogen. C:N = carbon nitrogen ratio. Ca = calcium. Mg = magnesium. K = potassium. BS = base saturation. TEC = total exchange capacity. CEC = cation exchange capacity. EC = electrical conductivity.

Table B.17. Significant correlations r > 0.5 ($r^2 > 0.25$) between vegetation and lower layer soil properties at bare and vegetated patches on peat mineral soil mix at Cell 18 thirteen years after reclamation (continued).

Bare	r	p	Vegetated	r	p
Sand vs forb cover	-0.91176	0.0113			
Silt vs forb cover	0.81168	0.0499			
Silt vs richness	0.84515	0.0341			
Clay vs live vegetation cover	0.84515	0.0341			
Clay vs moss cover	0.92582	0.008			

Table B.18. Significant correlations with r > 0.5 ($r^2 > 0.25$) between vegetation and upper layer soil properties at bare and vegetated patches on LFH mineral soil mix at Cell 16 thirteen years after reclamation.

Bare	r	p	Vegetated	r	p
Water retention at 30 kPa vs total cover	1	<0.0001	TN vs richness	-1	<0.0001
Water retention at 30 kPa vs forb cover	1	<0.0001	PR at 0 cm vs native richness	1	<0.0001
Water retention at 1500 kPa vs total cover	1	<0.0001	PR at 0 cm vs woody plant density	1	<0.0001
Water retention at 1500 kPa vs forb cover	1	<0.0001	PR at 30 cm vs grass cover	-1	<0.0001
Litter cover vs total cover	1	<0.0001	PR at 30 cm vs native cover	-1	<0.0001
Litter cover vs forb cover	1	<0.0001	Depth at maximum PR vs grass cover	-1	<0.0001
			Depth at maximum PR vs native cover	-1	<0.0001

TN = total nitrogen. PR = penetration resistance.

Table B.19. Significant correlations r > 0.5 (r^2 > 0.25) between vegetation and lower layer soil properties at bare and vegetated patches on LFH mineral soil mix at Cell 16 thirteen years after reclamation.

Bare	r	p	Vegetated	r	p
Exchangeable K vs live vegetation cover	1	<0.0001	pH vs grass cover	-1	<0.0001
			pH vs native cover	-1	<0.0001

K = potassium.

Table B.20. Significant correlations r > 0.5 (r^2 > 0.25) between vegetation and slope at bare and vegetated patches on peat mineral soil mix at SE dump four years after reclamation.

Bare	r	p	Vegetated	r	p
Slope % vs bare ground cover	0.82244	0.0035	N/A	N/A	N/A
Slope % vs live vegetation cover	-0.73624	0.0152			
Slope % vs total cover	-0.71275	0.0207			
Slope % vs richness	-0.65014	0.0418			
Slope % vs native richness	-0.6669	0.0352			