Early Vegetation Community Development and Dispersal in Upland Boreal Forest Reclamation

by

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Abstract

Re-establishment of appropriate vegetation communities is an important aspect of successful forest reclamation as they contribute to various ecosystem functions. In my research I explore how different coversoil materials (salvaged forest floor (FFM) and peat material), their placement depths, and underlying subsoil materials influence the early colonizing vegetation on an upland boreal forest reclamation site. Further, I investigated what effects the selection of tree species and their planting densities have on vegetation community development. As salvaged FFM contains propagules common of upland forests, it provided much higher richness and cover than when peat material was used as a coversoil. While material placement depth had little impact on vegetation, the type of subsoil material did play a role when placed beneath the coversoils, particularly with high phosphorous availability resulting in increased plant cover and species richness. Selection of tree species had little effect on the vegetation within the timeframe measured as seedlings were likely too small. Planting density had an impact early on with reduced vegetation cover in high density plots where seeding growth was high (in FFM). In a second study, I explored whether FFM islands would act as a nucleus for dispersal of forest vegetation throughout reclaimed landscapes. Vegetation egress and seed rain from the islands into adjacent peat material were examined to assess the dispersal mechanisms contributing to the egress. By the fourth growing season, species associated with FFM comprised a higher proportion of the vegetation cover than species associated with the receiving peat material up to 20m away from the island border. Although overall cover was low compared to in FFM areas, herbaceous, graminoid, and shrub species associated with the FFM were all present in the peat. Wind dispersed species were able to disperse further into the

surrounding peat material than species which utilized other dispersal methods. Despite seeds successfully dispersing from FFM areas, poor seed bed conditions in the peat limited seed retention and germination. However, dispersal into peat with vegetative reproductive structures appears promising as a result of the material's high nitrate concentrations and water holding capacity.

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Chapter 1: General Introduction

1.1 Surface Mine Reclamation in the Boreal Forest

Large surface mines have become an increasingly common feature of the boreal forest landscape as resource extraction operations have intensified. Although less floristically diverse than other forests (Shugart et al. 1992), the boreal forest is an important biome as it covers nearly a billion hectares in a circumpolar ring across the northern hemisphere (NRCAN 2016). Approximately a third of the boreal forest's area occurs in Canada, and it accounts for more than three quarters of the country's forested land (NRCAN 2016). Emphasis and research on appropriate forest reclamation practices have increased in conjunction with the growth in surface mining in the boreal forest.

During the mining process all merchantable timber is initially harvested, after which all ground vegetation is removed during soil salvage. The upper lift, or coversoil material, is usually salvaged to a depth of 30cm in fine texture soil and 15cm in coarse texture soil (Soil Quality Criteria Working Group 2004, Alberta Environment and Water 2011); this usually includes organic forest floor layers (L-F-H horizons) and mineral A and B horizons. However, more or less may be salvaged depending on the site conditions, particularly with regards to lowland Organic soils (Soil Quality Criteria Working Group 2004). The second lift, or root zone material, is salvaged until various physical and chemical criteria, including pH, sodicity, sodium adsorption ratios, and texture are no longer met and typically includes various mineral B and C horizons (Soil Quality Criteria Working Group 2004).

Salvaged soil can either be directly placed on active reclamation sites or stockpiled until needed. Direct placement is often preferred to stockpiling as it leads to faster ecosystem restoration (Bradshaw 2000) with greater vegetation establishment and reduced reclamation management costs as a result of the limited soil handling (Koch et al. 1996, Rokich et al. 2000, MacKenzie and Naeth 2010). Stockpiling soil has been found to cause significant leaching of nutrients and organic matter and decreases in viable propagules and the soil biota communities (Alberta Environment and Water 2011). Although direct placement is the preferred soil management technique, it is not always operationally feasible due to space availability or logistical challenges.

Once vegetation and salvageable soil have been removed, overburden materials are excavated. Overburden materials are those geologic formations which overlay the resource that are removed during the mining process. Overburden is generally placed in permanent, aboveground 'dump' areas. The reclamation process involves contouring of these overburden dumps to meet the landscape's hydrologic needs (Carroll et al. 2000, Salazar et al. 2002) and structural stability requirements. Once the overburden has been contoured, soil material is placed; this typically involves one to two meters of subsoil materials from the second lift which are then capped with 10 to 50cm of coversoil material from the upper lift (McMillan et al. 2007, Rowland et al. 2009, Macdonald et al. 2012). Once the soil cap is in place forest reclamation sites are then often planted with native tree seedlings (Parrotta et al. 1997, Macdonald et al. 2012).

Surface mining presents unique challenges that are associated with the landscape level removal and displacement of soil that are not associated with other disturbances such as in-situ oil and gas operations, forestry, forest fires, and insect outbreaks. In addition to nutrient availability and vegetation re-establishment, soil chemistry, structure, hydrology, and propagule banks are also abruptly and severely affected by surface mining processes (MacKenzie and Naeth 2010, Alberta Environment and Water 2011, Franklin et al. 2012). The high nitrogen, bulk density, soil temperature, and reduced soil moisture and propagule viability that result from soil excavation make vegetation re-establishment challenging in these areas (McMillan et al. 2007, Rowland et al. 2009). In addition to re-establishment of hydrologic regimes and soil processes, development of a structurally diverse vegetation community is critical as it contributes to forest floor development (Rowland et al. 2009) and various ecosystem functions, including nutrient and carbon cycling, energy flow (Nilsson and Wardle 2005; Gilliam 2007), soil stabilization, and water filtration (Carroll et al. 2000; see Table 1.1). .

1.2 Vegetation Re-Establishment

One of the main challenges in boreal forest reclamation is the re-establishment of a diverse vegetation community of native species (Macdonald et al. 2015a). This development is strongly influenced by the presence and dispersal of propagules as well as resource (*e.g.*

nutrients, water) availability (Kenkel et al. 1997). Recently there has been an increase in the use of planted native shrubs on reclamation sites (Strong 2000); however, the majority of boreal forest species are not yet commercially available (Macdonald et al. 2012, 2015a). This limitation has led to the exploration of alternative methods which can be used on reclamation sites to promote vegetation development.

Propagule banks contained within salvaged coversoil material have been found to be one of the most significant resources for initial vegetation community establishment (Paré et al. 1993, Koch et al. 1996, MacKenzie and Naeth 2010, Macdonald et al. 2015b, Schott et al. 2016). Coversoil salvaged from lowland sites is often predominately organic peat material, and as it developed below a lowland forest, the propagule bank contains species which are suited to mesic conditions (MacKenzie and Naeth 2010, Schott et al. 2016). Forest floor material (FFM) salvaged from upland sites is predominantly mineral material with some organic matter and contains propagules from species adapted to more xeric conditions (MacKenzie and Naeth 2010, Schott et al. 2016).

Use of FFM on reclamation sites has been found to produce vegetation communities with higher cover and overall species abundance as compared to the use of peat material, particularly of forest shrub and herbaceous species (MacKenzie and Naeth 2010, Schott et al. 2016). Forest floor material also has higher available potassium and phosphorous, as well as elevated microbial activity compared to peat material (McMillan et al. 2007, Pinno et al. 2012). However, peat material has lower bulk density and higher organic matter content, nitrogen availability, and water holding capacity than FFM (MacKenzie and Naeth 2010). Additionally, high vegetation cover in FFM has been found to reduce development of planted tree seedlings in some instances (Schott et al. 2016).

The expression of the propagule bank from coversoil material is influenced by a variety of factors, one of which is material salvage and placement depth. Too deep of a salvage will dilute the propagule bank by mixing the surface layers (containing seeds, rhizomes, etc.) with the deeper mineral soil material, whereas too shallow of a salvage is operationally challenging, expensive, and may not capture all of the surface layers (Tacey and Glossop 1980, Putwain and Gillham 1990, Grant et al. 1996, Koch et al. 1996, Rokich et al. 2000, MacKenzie and Naeth

2010). Additionally, while deeper coversoil placement prevents propagule desiccation (Wachowski et al. 2014, Landhäusser et al. 2015), it increases the probability of propagules being wasted by being buried too deeply for germination or emergence (Putwain and Gillham 1990; Grant et al. 1996; Rokich et al. 2000; Wachowski et al. 2014; Macdonald et al. 2015). Shallow treatments generally result in higher vegetation cover and richness initially; however, this trend generally does not persist long-term (Rokich et al. 2000, Holmes 2001, MacKenzie and Naeth 2010).

Soil chemistry, including nutrient availability, pH, sodium adsorption ratio (SAR), and electrical conductivity (EC), are other site characteristics that strongly influence the colonizing vegetation community (Rowland et al. 2009, Alberta Environment and Water 2011). Broadcast fertilizers have traditionally been used on reclamation sites to resolve nutrient deficiencies and promote initial tree seedling growth (Rowland et al. 2009, Pinno et al. 2012, Sloan and Jacobs 2013). However, broadcast application of fertilizers often focuses on nitrogen addition despite frequent deficiencies of potassium and phosphorous in reclamation soils (Rowland et al. 2009). The associated increase in nitrogen availability often results in increased cover by nitrophilous and ruderal plant species (Sloan and Jacobs 2013, Schott et al. 2016). Determining a nutrient application practice that contributes to initial vegetation community and tree seedling development without promoting the establishment of competitive graminoid and nitrophilous species is still needed.

In unmanaged and harvested forests the tree canopy exerts a strong influence on the understory vegetation community (Hart and Chen 2008). This is a result of the effect that different canopy species have on associated environmental, physical, and chemical conditions, including light availability and nutrient cycling (Macdonald and Fenniak 2007, Hart and Chen 2008). Broadleaf forests have higher richness in their understory communities, consisting primarily of herbaceous and shrub species, than mixedwood or conifer stands, with the latter having higher richness in ericaceous shrubs and bryophytes (Carleton and Maycock 1981; Reich et al 2001; Qian et al. 2003; Hart and Chen 2006). Tree seedlings are often planted on reclamation sites as this is the most effective approach in achieving canopy re-establishment

(Parrotta et al. 1997); manipulating planting prescriptions is anticipated to be a means of influencing the vegetation community development.

Applied nucleation is a reclamation revegetation technique which attempts to mimic and accelerate natural succession. This technique intends to simulate the process of woody species establishment in non-forested areas as a successional pathway to forest canopy development (Corbin and Holl 2012). Various iterations of the technique have been used in restoration projects, including planting of groups of tree seedlings, construction of bird perches and shelters, and soil and seed rain translocation from forested areas (Reis et al. 2010, Boanares and Azevedo 2014). One nucleation strategy of particular interest in the boreal forest is soil translocation through the strategic use of directly placed FFM (Alberta Environment and Water 2011, Naeth et al. 2013). Placement of FFM islands within larger, predominately peat reclaimed landscapes is expected to promote egress of forest species across the reclamation site that develop from the FFM propagule bank; however, this technique has had little implementation and testing.

1.3 Research Area

In Alberta, Canada, disturbed areas must be returned to sustainable ecosystems with equivalent land capabilities as those present in pre-disturbance conditions (Alberta Environment 2009). Equivalent land capability is determined through a combination of timber production, watershed functions, and wildlife habitat measures (Alberta Environment 2009). Coupled with this objective, reclamation practitioners are working towards developing approaches that speed up forest ecosystem development on reclamation sites (Macdonald et al. 2012) while focusing on capability rather than productivity (Powter et al. 2012).

All research presented in this thesis was conducted at the Aurora Soil Capping Study (ASCS), which is a large-scale reclamation experiment located at the Syncrude Aurora North Mine (57°20'01.2"N, 111°31'58.2"W). The ASCS was constructed on an overburden dump and was designed as a large collaborative study to test reclamation questions related to appropriate capping prescriptions over LOS material. The Aurora North Mine is located approximately 80km north of Fort McMurray, Alberta, Canada, and is a part of a concentration of surface mines in

Alberta located within the Athabasca oil sands region (AOSR). Oil sands surface mines only occur in areas where the bitumen rich McMurray formation, an oil sands deposit that developed in the Cretaceous period, is less than 75m below the surface (Conly et al. 2002). This corresponds to an approximate area of 480,000ha which can potentially be mined (Alberta Government 2014). While not contiguous, as of 2013 nearly 90,000ha have been disturbed; of this area, around 5500ha have been permanently reclaimed and around 100ha have received the required reclamation certification (Alberta Government 2014).

Geologic material present in oil sands overburden dumps are from the Cretaceous period and include marine shale and sandstone materials (Conly et al. 2002). Included in these dumps are also portions of the McMurray formation which does not meet the seven percent economical ore grade concentration (Ansley 1963). These overburden materials are generally not considered suitable for vegetation establishment as a result of environmental risks associated with the unweathered bitumen found within the materials (Conly et al. 2002). Even though bitumen is naturally occurring, there are concerns that the disruption, displacement, and placement of the overburden closer to the surface and in a new environment may pose a risk to receptors (M. Yarmuch personal communication).

For several reasons, uncertainty remains regarding appropriate soil cover design(s) for oil sands substrates that will facilitate forest development. These reasons include: 1) unique substrates in the region provide limited opportunities to apply soil cover design strategies from more established mine reclamation practices in other jurisdictions, and 2) relatively young reclamation record are available to date in the oil sands to apply learnings and validate soil reclamation requirements.

The AOSR is located in the north-eastern portion of Alberta in the central mixedwood natural subregion of the boreal forest. In Alberta, the boreal forest covers over half the province at nearly 39 million hectares; the central mixedwood natural subregion is the largest subregion in the province encompassing over a quarter of Alberta's total area (Natural Regions Committee 2006). Along with anthropogenic disturbances such as forestry and oil and gas extraction, forest fires and insect outbreaks are common in the subregion (Shugart et al. 1992). The subregion experiences short, cool summers and long, cold winters (Natural Regions

Committee 2006), with the majority of precipitation falling during the growing season from May to September (Government of Canada 2016).

The central mixedwood natural subregion is made up of a mosaic of upland and lowland sites. Upland areas, which make up about 52% of the subregion, primarily consist of Trembling aspen (*Populus tremuloides* Michx.) - White spruce (*Picea glauca* Moench.) mixedwoods (Natural Regions Committee 2006). The reference understory community for these mixedwood upland stands consist of *Viburnum edule* (Michx.) Raf., *Rosa acicularis* Lindl., *Alnus crispa* Chaix., *Shepherdia canadensis* (L.) Nutt, *Elymus innovatus* Link., *Cornus canadensis* L., *Aralia nudicalis* L., and *Rubus pubescens* Raf. (Natural Regions Committee 2006). Upland forests that have developed on coarse texture material, particularly in the eastern part of the subregion, are dominated by Jack pine (*Pinus banksiana* Lamb.) stands (Natural Regions Committee 2006). These stands cover about 10% of the subregion and often have *Arctostaphylos uva-ursi* (L.) Spreng and various lichen species in the understory (Natural Regions Committee 2006). Wetlands, consisting of treed fens and bogs, cover nearly half the central mixedwood (Natural Regions Committee 2006). These species-poor lowland sites are dominated by Black spruce (*Picea mariana* (Mill.) Britton), although they can include *Larix laricina* (Du Roi) K. Koch, *Ledum groenlandicum* Oeder, and various *Salix* species, feather mosses, and peat mosses (Natural Regions Committee 2006). Grasslands, while rare in the subregion, can occur in areas within *Pinus banksiana* or *Picea mariana* forests on coarse, rapidly drained soils (Natural Regions Committee 2006). Species found in these grassland patches include *Oryzopsis pungens* (Torr.) Romasch, *Festuca saximontana* Rydb., and various dryland sedges (Natural Regions Committee 2006). In mesic to rich areas of high disturbance throughout the subregion, *Calamagrostis canadensis* (Michx.) P. Beauv. has been known to become dominant (Natural Regions Committee 2006).

Gray Luvisols are the dominant upland soils of the subregion and are associated with the aspen-spruce mixedwood stands (Natural Regions Committee 2006). These soils are characterized by a diagnostic Bt horizon and often include litter, fibric, and humic (L- F - H) horizons (Soil Classification Working Group 1998). These soils develop in areas with a mean annual soil temperature less than $8^{o}C$ and on calcareous parent geologic material (Soil

Classification Working Group 1998). Eutric and Dystric Brunisols occur in the areas with coarse textured sands where pine stands occur (Natural Regions Committee 2006). These are distinguished by a weakly developed Bm horizon and have little to no Ah horizon, although they can support the development of LFH horizons (Soil Classification Working Group 1998). Organic soils can be found in the lowland areas, with Terric Mesisols being dominant (Natural Regions Committee 2006). These soils are saturated with water for prolonged periods of time and are characterized by a mineral layer at least 30cm thick located beneath the organic material (Soil Classification Working Group 1998).

1.4 Objectives and Thesis Structure

The overall objective of this research was to explore the effects that reclamation material selection and placement have on the establishing vegetation community in upland boreal forest reclamation following surface mining.

Chapter 2 examines the effects that various coversoil material types, coversoil material placement depths, total reclamation material capping depth, and underlying soil material types have on the colonizing vegetation community. Additionally, the effects that different planted tree seedlings and planting densities have on the vegetation were also tested. The plant community was assessed in terms of species richness, total vegetation cover, and the vegetation composition over three growing seasons.

Chapter 3 presents results from a study focusing on the egress of vegetation out of areas capped with salvaged coversoil from upland forests into areas capped with salvaged lowland soils. This study included examination of both the vegetation community and seed rain along the material borders. Species were categorized based on dispersal methods in order to determine which mechanisms were most effective at moving from FFM islands into peat material.

Chapter 4 reviews the key findings of the previous two chapters and synthesizes these points. Application suggestions and management implications from these results are then outlined. Study limitations and related areas of future research are also discussed in this chapter.

Tables

Table 1.1: Ecosystem functions which vegetation and soil (both coversoil and subsoil material) have been found to contribute to, in both natural and reconstructed forest stands.

	Ecosystem Function	References
Vegetation		
	Soil stabilization	Carroll et al. 2000
	Water filtration	Carroll et al. 2000
	Nutrient cycling	Nilsson and Wardle 2005; Gilliam 2007
	Carbon cycling	Gilliam 2007
	Energy flow	Gilliam 2007
Soil		
Coversoil	Water storage	Dominati et al. 2010; Macdonald et al. 2012
	Water filtration	Dominati et al. 2010; Macdonald et al. 2012
	Nutrient cycling	Dominati et al. 2010; Macdonald et al. 2012
	Carbon cycling	Macdonald et al. 2012
	Microbial habitat	Macdonald et al. 2012
	Vegetation establishment	Li and Fung 1998
Subsoil	Water storage	Dominati et al. 2010; Macdonald et al. 2012
	Water filtration	Dominati et al. 2010; Macdonald et al. 2012
	Nutrient storage	Dominati et al. 2010; Macdonald et al. 2012
	Carbon cycling	Macdonald et al. 2012
	Vegetation stabilization	Dominati et al. 2010; Macdonald et al. 2012
	Microbial habitat	Macdonald et al. 2012

Chapter 2: Effects of surface and subsoil material, tree species selection and planting density on early vegetation community development.

2.1 Introduction

Resource extraction is a major activity in the Canadian boreal forest; apart from forestry and in-situ operations, large-scale surface mining is a significant component of this activity. Surface mines require the removal of vegetation, soil, and overburden materials to access the resource. This is a severe disturbance which alters the landscape and hydrological regime. Reclamation operations often aim to return mined areas back to sustainable ecosystems with equivalent land capabilities as those present in pre-disturbance conditions (Powter et al. 2012).

Overburden material excavated during mining is often direct-hauled to another location rather than returned to the mine pit. Overburden is generally placed in aboveground 'dump' areas, which are contoured into large-scale closure landforms that provide the base for upland reclamation. The chemical and physical characteristics of the overburden influence its reclamation capability, or conversely, its limitations or potential environmental risk in the closure landscape. Applying an appropriate soil cover design (soil reclamation material(s) and reclamation capping depth(s)) for overburden reclamation is a practical and effective strategy to mitigate potential limitations or environmental risks of reclaimed substrates.

Soils are the foundation of the reclaimed ecosystem, and as such, placing a suitable rooting medium is a critical step in boreal forest reclamation (Macdonald et al. 2012, 2015a, Zipper et al. 2013). They contribute to a variety of ecosystem functions including water storage and filtration, nutrient cycling, and vegetation stabilization (Dominati et al. 2010; see Table 1.1). Undisturbed forests have a mosaic of soil horizons and characteristics across their landscape; while duplicating this variability is unachievable operationally, attaining a level of belowground complexity should still be attempted (Macdonald et al. 2012). Physical soil processes such as weathering and horizon differentiation may not be discernable on these reclaimed sites for centuries (Bradshaw 2000), further emphasizing the need to artificially create belowground heterogeneity during initial soil placement. Two key components of the reclamation soil profile are the materials used for the coversoil and the underlying subsoil layers. This configuration is intended to mimic soil profiles, with the coversoil serving as the surface organic and mineral layers (equivalent to LFH and A horizons) and the subsoil as the lower mineral horizons.

The coversoil layer has three main functional roles: providing a seed bed for the establishing vegetation (Pinno et al. 2012), storing water to be available to vegetation in the short term, and cycle and suppling nutrients for vegetation in the short- and long-term (Macdonald et al. 2012). In addition to these three roles, many studies have also found that the materials used for the coversoil layer often have propagule banks that are needed for early vegetation community establishment on reclamation sites (Paré et al. 1993, Schimmel and Granström 1996, Greene et al. 1999, MacKenzie and Naeth 2010, Macdonald et al. 2015b).

Mine reclamation in the boreal forest region often uses salvaged peat and forest floor material (FFM) as coversoils. Peat material is salvaged from lowland areas such as bogs and fens and is composed primarily of organic material. If the underlying mineral material of peat salvage areas is conducive to mixing with the peat (*i.e.* coarser textured), over-stripping of the peat to capture some of the underlying mineral material is often done to create a peat-mineral mix coversoil. Forest floor material (FFM) is salvaged from upland forest sites and includes the organic layers (LFH), mineral A horizons, and potentially a portion of the B horizon. These types of coversoil materials have been found to have different microbial communities, propagule banks, and nutrient availability (see Greene et al. 1999, Grant and Koch 2007, MacKenzie and Naeth 2010, Hahn and Quideau 2013). Forest floor materials (FFM) contain a propagule bank of species suited to upland site conditions, while materials salvaged from lowlands contain species mostly adapted to wetter lowland site conditions (Fung and Macyk 2000, MacKenzie and Naeth 2010, Schott et al. 2016). Balancing salvage and placement depth of these materials is also critical as it relates to the availability and establishment success of viable propagules. Deeper soil salvage will result in greater propagule dilution and deeper coversoil placement results in loss of viable propagules owing to deep burial (Tacey and Glossop 1980, Putwain and Gillham 1990, Grant et al. 1996, Rokich et al. 2000). Alternatively, placing surface material at shallow depths can lead to reduced propagule viability due to desiccation from exposure at the surface (Wachowski et al. 2014, Landhäusser et al. 2015).

The main roles of the subsoil material in reconstructed soils are for long-term water storage as well as vegetation stabilization by allowing for deeper root penetration (Li and Fung 1998, Macdonald et al. 2012). To meet these requirements, the material type, placement depth, and configuration of reclamation soil prescriptions need to be considered (Huang et al. 2011). To meet the functional roles of subsoil it is essential that the material is conducive to root growth and vertical root system expansion (Burger et al. 2005, Macdonald et al. 2012). Therefore, excessive physical compaction (from heavy equipment) or high salinity in subsoils should be avoided when possible. However, some variability in material texture and compaction levels can be beneficial as reclamation soil profiles with textural discontinuities can have increased water availability at the interfaces (Leatherdale et al. 2012).

Tree canopy composition is also considered a main driver of the vegetation community development in forest environments as a result of the impact on light availability as well as on soil physical and chemical properties (Macdonald and Fenniak 2007, Hart and Chen 2008). In the boreal forest, light availability is considered a limiting resource for understory vegetation (Légaré et al. 2002). Light availability is primarily influenced by canopy composition and structure (Canham and Burbank 1994, Messier et al. 1998). Deciduous broadleaf-dominated forests which transmit more light are often associated with higher richness and diversity, particularly of herbaceous and shrub species, than conifer dominated stands (Hart and Chen 2006, Macdonald and Fenniak 2007). Natural stands containing a mix of deciduous and conifer trees have been found to support higher richness of understory species than pure conifer stands (Saetre et al. 1997, Pitkänen 2000).

While there are relatively few native tree species in the boreal biome compared to other forest biomes (Shugart et al. 1992), tree species selection is an important part of reclamation planning. Trembling aspen (*Populus tremuloides* Michx.) is often recommended as a foundational species for use in boreal forest reclamation sites due to its fast growth, drought tolerance, and vegetative reproduction (Macdonald et al. 2012); however, upland sites across the boreal forest are also often dominated by coniferous species. Tree species selection has also been found to influence ectomycorrhizal species establishment on young reclamation sites in the boreal (Hankin et al. 2015), further emphasizing the importance of tree species selection in reclamation planning. Planting density is also an important aspect to consider for reclamation. Forestry planting density standards are typically used in reclamation in Canada (1500 – 2500 stems ha^{-1} (sph)) although higher densities ($\geq$10,000 sph) have been used in other reclamation projects globally (Macdonald et al. 2012). Planting trees at high densities is believed to reduce establishment and competition from weedy species by achieving faster canopy closure (Macdonald et al. 2012).

This study aims to identify the impacts of different soil cover designs (material type, configuration, and placement depth) as well as revegetation practices (tree species selection and planting density) on the early colonizing vegetation community of upland boreal forest reclamation sites. The influence of these treatments on the early colonizing vegetation were assessed by measuring species richness, vegetative cover, and the community composition in the second and fourth growing season. Cover designs that utilize salvaged soil from upland forests were anticipated to have a more diverse vegetation community compared to designs that used only mineral subsoil material or salvaged peat from lowland areas. Coversoils at different placement depths were not anticipated to have different communities because the depth of salvage of these materials was the same. The subsoil material type and thickness underlying the coversoil is likely not playing a large role in the early stages of recolonization as the roots might not have reached these deeper layers. Similarly, the impact of planted trees species and their density on the vegetation community is anticipated to be minimal as the canopy has not fully developed.

2.2 Methods

2.2.1 Research Area

Research for this project took place at the Aurora Soil Capping Study (ASCS), which is a large-scale reclamation experiment (36ha) located at the Syncrude Aurora North Mine (57°20'01.2"N, 111°31'58.2"W). The Aurora North Mine is located approximately 80km north of Fort McMurray, Alberta, Canada, and is one of two active oil sand open-pit mines held by Syncrude Canada Ltd (Syncrude Canada Ltd 2015). Syncrude mines are located within the Alberta central mixedwood natural subregion, an area made up of a mosaic of upland and lowland sites. Upland forests are typically either mixedwood stands of White spruce (*Picea* *glauca* Moench.) and Trembling aspen (*P. tremuloides*) on Luvisolic soils or Jack pine (*Pinus banksiana* Lamb.) stands on Brunisolic soils (Soil Classification Working Group 1998, Natural Regions Committee 2006). Lowland sites are typically either fens or bogs dominated by Black spruce (*Picea mariana* Mill.) that have developed on poorly drained Organic soils (Soil Classification Working Group 1998, Natural Regions Committee 2006).

In the 2013 growing season (May to September) at the ASCS, the average daily temperature was 16.0^{o}C and rainfall totalled 318.6mm. During the dormant season (October 2013 to April 2014), average daily temperature was -10.4^{o}C. The 2014 growing season had an average daily temperature of 14.5^{o}C with 343.1mm of total rainfall. The following dormant season was slightly warmer than its predecessor at -9.6^{o}C. In the final growing season associated with this research (May to September 2015), the daily average temperature was 14.8^{o}C. Most notably the rainfall was substantially lower in this growing season with only 208.0mm of rainfall in total falling on the site. Climate normals during the growing season for the region (1981-2010) were an average daily temperature of 13.4^{o}C and precipitation totalling 284.3mm (Government of Canada 2016).

2.2.2 Site Construction and Material Characteristics

The ASCS was built on a lean oil sand (LOS) overburden dump; the LOS material had a sandy loam texture, a neutral pH, and an average bitumen content of 2.7% by weight (Table 2.1). Thirteen soil cover design treatments were established which vary in material type, their vertical arrangement, and thickness. A range of coversoil and subsoil materials make-up the treatments of the ASCS. The study incorporated two coversoils: peat and FFM, and four subsoils: two types of Bm, BC/C, and C horizons.

Peat for the coversoil was salvaged from a lowland area within the mine footprint to a maximum depth of approximately three meters and was directly placed on the site. The material was 34% organic matter by weight, had a pH of 7.4, high concentrations of nitrate, potassium, and sulphate, and low concentrations of phosphorous as compared to the other soil materials used on the site (Table 2.1). Based on the low electrical conductivity (EC) and sodium adsorption ratio (SAR) values and basic material pH, the peat used at the ASCS is considered suitable as a reclamation coversoil (Soil Quality Criteria Working Group 2004).

Forest floor material (FFM) for the coversoil was salvaged from an upland forested area dominated by Jack pine (*P. banksiana*) which developed on predominantly sand textured Brunisolic soils. This material was salvaged to a depth of approximately 15cm to capture the forest litter layers (LFH), the underlying A horizons, and potentially a portion of the B horizons. Like the peat salvage, FFM was directly placed on the ASCS. The FFM was sandy in texture with a pH of 5.6. In comparison to the other soil materials used at the ASCS, the FFM had high concentrations of ammonium, phosphorous, and potassium, and low concentrations of nitrate (Table 2.1). While the sandy texture of the FFM suggests the material may be a poor reclamation coversoil material, based on its chemical characteristics, including pH as well as low EC and SAR, the FFM used at the ASCS is considered a good soil substrate for reclamation (Soil Quality Criteria Working Group 2004).

The subsoil materials of the study were salvaged from Brunisolic soils within the mine footprint. The differences in subsoil materials varied mostly in time of salvage, salvage depth, pH, and phosphorous concentrations (Table 2.1). Subsoils (Bm1) and (Bm2) have different Pleistocene parent geologic materials; however, they were both salvaged from a depth of 15 to 50cm, which is the general range of the B horizon for upland soils in the region. Both materials were salvaged and stockpiled prior to the construction of the overburden dump during the winter of 2007/08. The Bm1 subsoil had a sandy texture and a lower bulk density and pH than the other subsoil materials used (Table 2.1). While this material had similar concentrations of ammonium, nitrate, potassium, and sulphate to the other subsoil materials, it had higher phosphorous concentrations, similar to that of the FFM (Table 2.1). The Bm2 subsoil had the highest pH and the lowest phosphorus concentration of the four subsoils used (Table 2.1).

The BC/C subsoil was salvaged from a depth of 50 to 100cm from the same location as subsoil (Bm1). This salvage depth is the general range of the BC horizon and upper depth of the C horizon in Brunisolic soils. This material was salvaged in the winter of 2007/08 and was stockpiled until placed on site. The material was also sandy in texture but had a higher pH than subsoil (Bm1) and a higher phosphorous concentration than subsoil (Bm2), although this was still lower than subsoil (Bm1) (Table 2.1).

The subsoil (C) material was a deep salvage of the B and C horizons from a depth of 15 to 250cm. The salvage area was the same as the FFM salvage area, which was adjacent to the salvage area of subsoils (Bm1) and (BC/C). As was done with the FFM and peat, subsoil (C) was directly placed on the ASCS after salvaging. The material was also sandy in texture; additionally, the phosphorous concentration was lower than subsoil (Bm1) and the pH was lower than subsoils (Bm2) and (BC/C) (Table 2.1).

Based on their texture, pH, EC, and SAR, all of the subsoils used at the ASCS are suitable rooting material for upland reclamation (Soil Quality Criteria Working Group 2004). While the consistent sandy texture of all four subsoil types is quality of poor reclamation material, the low EC values (<2 dS m^{-1}) values for all the subsoil materials is characteristics of good reclamation material (Table 2-1; Soil Quality Criteria Working Group 2004). The pH values between the materials range from good (subsoil (Bm1)), fair (subsoil (BC/C) and subsoil (C)) and poor (subsoil (Bm2)) (Table 2-1; Soil Quality Criteria Working Group 2004).

Soil placement at the ASCS began in 2011 and was completed prior to the 2012 growing season. In 2012 soil samples and field measurements were collected to confirm placement depths and evaluate soil physical and chemical characteristics for each plot of the study. Further details regarding the physical and chemical characteristics of the various soil materials used at the ASCS are presented in Table 2.1. All soils information presented in this paper was provided by NorthWind Land Resources Inc. and Alberta Innovates-Technology Futures.

2.2.3 Experimental Design

The ASCS was set up as a split-plot design on a total area of 36ha (Figure 2.1). The plot effect is the soil capping treatment and the tree planting treatments the split effect. Thirteen capping treatments were randomly assigned across the site in one-hectare cells and replicated three times (Figure 2.2). The thirteen capping treatments varied in coversoil (peat or FFM) over one or two subsoil horizons. The peat coversoil treatments were placed at two depths: 10 or 30cm and one treatment is a single lift of 30 cm peat coversoil with no underlying subsoil. Forest floor material (FFM) was placed at a depth of 10 or 20cm underlain by different subsoil material types and configurations. To test the impact of total capping depth three treatments had a total capping depth of 30, 60, and 100 m, respectively, while all other treatments had a total reclamation soil material capping depth of 150cm.

2.2.4 Planting Treatments

In May 2012 planting of native tree and shrub species took place at the ASCS. Within each treatment cell (one hectare), three single species and one mixed species seedling plots (25m × 25m each) were established with a minimum buffer of 10m between plots (Figure 2.1). Commercially grown, one-year-old seedlings of trembling aspen, jack pine, and white spruce from a local seed source were planted. All plots were hand-planted at a regular 1 × 1m spacing (10,000 seedlings ha^{-1} (sph)) by a local tree-planting contractor. In addition, a FFM and peat coversoil treatment (treatments 8 and 10) received a second set of four tree plots planted at a low density of 2000sph (spacing 2.3m). In total, 180 tree plots were planted. Areas outside the tree plots within each cell were planted with a mixture of the same three tree species at a density of approximately 2,000sph. Three native shrub species (Pincherry (*Prunus pensylvanica* L.f.), Green Alder (*Alnus crispa* Chaix.), and Saskatoon (*Amelanchier alnifolia* (Nutt.) Nutt. ex M. Roem.)) were also planted in these areas at a density of approximately 800sph.

2.2.5 Vegetation Measurements

Unplanted vegetation was measured by two parameters in each tree plot: percent cover and presence/absence by species. Percent cover was assessed in two sampling quadrats (subsamples; 1.41m × 1.41m) located in the northeast and southwest corner of each tree plot. Quadrats were placed approximately seven meters from the plot border to allow for a sufficient buffer from the tree plot edge. Within each quadrat, individual species were identified and their percent cover was visually estimated. Cover was estimated to the nearest 1%; if less than 1%, cover was either determined to be 0.5% or trace (0.001%). To ensure consistency of the cover estimates, researchers performing the task calibrated estimate assessments several times a day and used Coroplast cut-outs (1% and 5% of the quadrat size) to help estimate cover more accurately. The measurements from the two subsamples were averaged to provide a percent cover value for each species for each tree plot.

Presence/absence was assessed by performing walkthroughs of each tree plot; this was done to determine the species richness. Walkthroughs were done by at least two researchers at a time; individuals spaced themselves three meters apart across the perimeter of the plot and walked forward. Individuals identified and called out species as they were seen while walking through the plot. Four passes were done to cover the full plot while maintaining three meters between researchers without double sampling any part of the plot.

Sampling of the tree plots for both percent cover and presence/absence of unplanted species took place from July 16-21, 2013, and July 8-14, 2015. Whenever possible, vegetation was identified to species in the field; when that was not possible the species was collected, pressed, and later identified. Of the 119 species observed across the ASCS, 16 could not be identified to the species level. These specimens were given a consecutive number behind the Genus (ex. *Salix* sp1) and the sample was kept on file to allow for comparison with other unidentified specimens. All scientific species nomenclature is based on Flora of Alberta (Moss 1994). A list of all species identified at the ASCS in 2013 and 2015 is provided in Appendix A.II.

2.2.6 Statistical Analyses

All analyses, unless otherwise mentioned, were done in R software, version 3.2.2, 64 bit (R Core Team 2015).

Analyses of physical and chemical characteristics of the various soil materials used on the site were done with a two-way Analysis of Variance (ANOVA) based on a full factorial design. These analyses were run using the aov function from the stats package (version 3.2.2) with α=0.1 (R Core Team 2015). Normality of the ANOVA residuals were tested using the Shapiro-Wilk test with the shapiro.test function from the stats package (version 3.2.2; R Core Team 2015) and the homogeneity of variance of the ANOVA residuals were tested using Levene's test with the leveneTest function from the car package (version 2.2-1; Fox and Weisberg 2011). Significant differences between the soil materials were determined with a Bonferroni adjustment α using the LSD.test function in the agricolae package (version 1.2-3; de Mendiburu 2015).

Separate models were run to test for treatment effects on percent cover and species richness. To test for the change of percent cover and species richness in time (Y) and with different coversoil materials (CM) and planted tree species (TS), data were analysed as a repeated measures split plot design with treatment replication as a random error factor. The repeated measures fixed effect for Model 1 was year with two levels, four levels of coversoil material as the main plot fixed effect (interaction of Y:CM), and four levels of planted trees as the split plot fixed effect (interaction of Y:TS, CM:TS and Y:CM:TS) were used. To maintain a balanced design with subsoil (Bm2) and subsoil (C), which only had one treatment each, three peat (treatments 1, 6, 10) and FFM (treatments 7, 8, 9) treatments were averaged and these values were used for analyses. Total percent cover and total species richness were analyzed with a linear mixed effect model, using the lme function from the nlme package (version 3.1-121; Pinheiro et al. 2015). For all analyses, the assumptions of normality and homogeneity applied; if data were found to violate the assumptions they were transformed logarithmically. This was done for both percent cover and species richness data. When statistically significant effects were found at α=0.1, post-hoc tests were conducted with an adjusted α using Tukey's honest significant difference method (Yandell 1997).

The potential effects of year, coversoil material, planted tree species, and their interactions were also tested on the community composition using the vegetation cover data. This was analyzed with a permutational multivariate analysis of variance (perMANOVA) using the adonis function from the vegan package (version 2-3-2; Oksanen et al. 2015). When statistically significant effects were found at α=0.1, post-hoc tests were done with a manually adjusted α based on the number of comparisons being done. To determine which species were representative of the significant relationships identified in the perMANOVA analyses, indicator species analyses were run using the multipatt function from the indicspecies package (version 1.7.4) with an α=0.1 (De Caceres and Legendre 2009).

Community composition was also analyzed by running a non-metric multidimensional scaling (NMDS) ordination on the vegetation cover data. This NMDS was run on an untransformed data matrix with a random starting configuration, a stability criterion of 0.00005, the Bray-Curtis distance measure, and the Wisconsin-style double standardized scaling using the metaMDS function from the vegan package (version 2.3-2; Oksanen et al. 2015). Two dimensions were used for the final graph of the NMDS, including ellipses showing 95%

confidence intervals and vectors showing significant association with the ordination (α=0.002). Ellipses for the NMDS were calculated using the ordiellipse function and vectors were determined using the envfit function, both from the vegan package (version 2.3-2; Oksanen et al. 2015).

Model 2 tested for the effects of planted tree density, coversoil placement depth, total capping material depth, or subsoil material type on the percent cover and species richness. For this Model only 2015 vegetation data was used, and FFM and peat treatments were analyzed separately. The assumptions of normality and homogeneity were violated and transformations did not resolve the normality issues; thus permutational analyses were used. Model 2 was a mixed model and was run with planned comparisons to test the remaining research questions as outlined in the introduction.

To test the first research question addressed with Model 2, any potential effects of planted tree species (TS), planted tree density (PD), and their interaction were analyzed. Unlike the rest of the ASCS, the tree density cells were set up as a two-factor factorial randomized complete block design. The first fixed factor had four levels of tree species and the second fixed factor effect had two levels of planting density (interaction of TS:PD), and cell was an error factor. The remainder of the analyses with this model were done based on a split plot model. To test the second research question addressed with the model, any potential effects of coversoil placement depth (SD), planted tree species (TS), and their interaction were analyzed. The main plot fixed effect had two levels of placement depth, the split plot fixed effect had four levels of planted tree species (interaction of SD:TS), and treatment replication was a random error factor. To test the third research question addressed with the model, any potential effects of total capping depth (CD), planted tree species (TS), and their interaction were analyzed. The main plot fixed effect had four levels of capping depth, the split plot fixed effect had four levels of planted tree species (interaction of CD:TS), and treatment replication was a random error factor. To test the fourth and final research question addressed with the model, any potential effects of subsoil material type (ST), planted tree species (TS), and their interaction were analyzed. The main plot fixed effect had three levels of subsoil material type, the split plot fixed effect had four levels of planted tree species (interaction of ST:TS), and treatment replication was a random error factor.

All analyses were run on total percent cover and total species richness data and were analyzed with a two-way permutational Analysis of Variance (permANOVA) using the aovp function from the lmPerm package (version 1.1-2) with an α=0.1 (Wheeler 2010). When significant effects or interactions were found, pairwise comparisons were done using Tukey's honest significant difference α adjustment method (Yandell 1997) with the TukeyHSD function from the stats package (version 2.15.1; R Core Team 2012). All univariate statistical analyses for the second model were done in R software, version 2.15.1, 64 bit (R Core Team 2012).

Differences in community composition were explored using a perMANOVA for each of the questions addressed in Model 2. Two-way perMANVOAs were run with the same fixed main and split plot effects and random effect as the univariate analyses. However, when significant effects or interactions occurred pairwise comparisons were adjusted according to the Holm method (Holm 1979). Adjustments to the p-values from perMANOVA pairwise comparisons were done using the p.adjust function from the stats package (version 3.2.2; R Core Team 2015). As was done with Model 1, representative species of the significant relationships identified in the Model 2 perMANOVAs were identified by running indicator species analyses.

2.3 Results

2.3.1 Coversoil Material Type and Planted Tree Species

2.3.1.1 Vegetation Cover and Richness

Between 2013 and 2015 total plant cover did not significantly vary; however, there was a significant year by coversoil material interaction (Table 2.2). Cover increased in peat and decreased in subsoil (Bm2) while total cover did not change between measurement years in FFM and in subsoil (C) (Figure 2.3). Coversoil had a significant effect on total plant cover and all coversoil materials were significantly different from one another (Table 2.2). Over both measurement years FFM had the highest average vegetation cover (6.18%), subsoil (Bm2) had the second highest (2.09%), followed by peat (0.42%) and subsoil (C), which had the lowest vegetation cover (0.03%). The type of tree species planted on the different coversoil materials had no effect on total plant cover (Table 2.2).

The number of species (total species richness) was similar between 2013 and 2015; however, the type of coversoil material had a significant effect on the number of species found (Table 2.2). Overall FFM had significantly higher richness than the other coversoils with an average of 32 species. Subsoil (Bm2) had 13 species, peat 10 species, and subsoil (C) seven species, none of which were significantly different from each other (Figure 2.4). However, there was a significant coversoil and tree species interaction for species richness (Table 2.2). The type of tree planted had no significant effect on species richness on FFM, peat, or subsoil (Bm2) materials, while subsoil (C) plots planted with spruce and pine had higher species richness than plots planted with aspen or mixed species (Figure 2.4).

2.3.1.2 Unplanted Vegetation Community Composition

There was an overall shift in the community cover composition between 2013 and 2015 across the entire ASCS (Table 2.2). The community associated with the 2013 growing season had six indicator species, three of which were annual forbs, including *Lepidium densiflorum*, *Geranium bicknellii*, and *Polygonum aviculare*, which had disappeared by the 2015 growing season. The other three species were present but did not play a significant role in defining the 2015 plant community. The indicator species for the 2015 season included a more diverse array of plant functional groups, two were volunteer native tree species (*P. tremuloides* and *P. banksiana*), two were graminoid species (*Festuca saximontana* and an unidentified *Carex* species), and two were annual forbs (*Aster laevis, Commandra umbellata*). Of these species, only *A. laevis* and *F. saximontana* had emerged on site in 2013. Tree species had no effect on the vegetation community (Table 2.2).

There was also a significant interaction between year and coversoil type on the vegetation community (Table 2.2) associated with significantly different communities in 2013 and 2015 in FFM and peat (p=0.017 for both). The communities in the two subsoil treatments were not significantly different between the measurement years. The 2013 FFM community was characterized by a variety of weedy annuals such as *P. aviculare* and *Erigeron canadense*, and large grasses such as *Agropyron trachcaulum* v. *glaucum* and *Calamagrostis inexpansa*. The 2015 community had fewer weedy annuals and large grass species and instead had volunteer tree species (*P. tremuloides* and *P. banksiana*) and a shrub species (*Rubus idaeus*) in addition to annual forbs (*A. laevis* and *C. umbellata*) and bunchy graminoids (*F. saximontana*, *Carex rossii*, and *Poa palustris*) as indicator species. The differences between the 2013 and 2015 peat vegetation communities were subtler, likely a result of the overall low plant cover in these plots. The 2013 community had a single indicator species (an unidentified *Carex* species) while the 2015 community had *Salsola pestifer*, volunteer *P. tremuloides,* and *C. inexpansa*.

Vegetation community composition was also significantly affected by the coversoil material type (Table 2.2). When the communities for each coversoil were combined for the two years, only FFM and subsoil (Bm2) were found to be significantly different from each other ($p=0.100$). This is evident in the NMDS as the 2013 and 2015 ellipses for many of the coversoils overlap (Figure 2.5). However, indicator species analysis of the coversoil materials found 30 unique indicator species for FFM, five unique indicator species for peat, one for subsoil (Bm2) and none for subsoil (C). In the NMDS, FFM plots loaded to the left of the first axis and to the center of the second axis with significant species scores associated with various grasses, forbs, and shrubs (Figure 2.5). Peat plots were fairly scattered in 2013 although they tended to load to the right of the first axis but spread throughout the second axis. In 2015, communities became more similar in peat and loaded to the center of the first axis and the bottom of the second axis. In 2013, there were no particular species driving the peat communities; however, in 2015 three species, two graminoids (*Muhlenbergia glomerata* and an unidentified *Carex* species) and one invasive ruderal forb (*S. pestifer*) had strong association with the vegetation community on peat (Figure 2.5). While the perMANOVA and indicator species analyses did not find significant differences between the two measurement years for the subsoil materials, some emerging patterns are evident within them from the NMDS. Subsoil (Bm2) plots loaded to the center-left of the first axis and top of the second axis in both 2013 and 2015, with a dramatic reduction in the size of the confidence ellipses occurring between the two years. The species scores primarily associated with this direction were two grasses (*A. trachycaulum* var *trachycaulum* and *Hordeum jubatum*; Figure 2.5). Of all the soil materials, subsoil (C) was the least defined, with plots loading across the second axis and from the center to the right of the first axis, with no clear reduction in ellipses size between the two measurement years (Figure 2.5).

2.3.2 Tree Density

In the 2015 growing season, tree plots planted at 2000sph had significantly higher average vegetation cover than plots planted at 10,000sph in FFM (Table 2.3; Figure 2.6). Species richness and community composition did not significantly differ between density plots in FFM (Table 2.3). In peat, high and low density planted tree plots did not differ in vegetation cover, species richness, or community composition (Table 2.3).

2.3.3 Coversoil Placement Depth

There was no significant difference in total cover, species richness, or community compositions when FFM was placed at either 10 or 20cm (Table 2.3). The placement depth of peat also did not affect species richness (Table 2.3); however, vegetation cover was higher in plots with 30cm of peat as compared to 10cm (Figure 2.7). The community composition was also significantly different between the two peat placement depths (Table 2.3). The two treatments shared *Muhlenbergia glomerata* as an indicator species but the deep treatment also had an unidentified *Carex* species as an additional indicator species.

2.3.4 Total Capping Material Depth

Vegetation cover and community composition did not differ between treatments with 30, 60, 100 and 150cm total capping depths (Table 2.3). Species richness was significantly higher in the 30 and 60cm total capping depths compared to the deeper depths (Figure 2.10).

2.3.5 Subsoil Material Type

When placed below FFM, the type of subsoil material significantly influenced vegetation cover and species richness (Table 2.3). FFM over subsoil (BC/C) had less than half the cover than FFM placed over subsoil (C) or subsoil (Bm1), which did not have significantly different cover from each other (Figure 2.8). Species richness was highest when FFM was placed over subsoil (Bm1) as compared to FFM over subsoil (BC/C) and subsoil (C), which were not different (Figure 2.8).

The FFM treatments with different underlying subsoil treatments also developed different vegetation communities (Table 2.3). When FFM was placed over subsoil (BC/C), the community composition was characterized by *Carex tonsa*, which was significantly different from when FFM was placed over subsoil (C) or subsoil (Bm1). *Elymus innovatus* and *Vaccinium myrtilloides* were the indicator species when FFM was placed over subsoil (C), which FFM over subsoil (C) shared as indicator species with FFM over subsoil (Bm1). Additionally, one shrub species (*R. idaeus*), two grasses (*A. trachycaulum var trachycaulum* and *Hierochloe odorata*), and two forbs (*Trientalis borealis* and *Commandra umbellata*) were also indicator species for FFM over subsoil (Bm1). The communities associated with FFM over subsoil (C) and FFM over subsoil (Bm1) were not significantly different from one another.

Underlying subsoil material also influenced vegetation cover and plant communities with peat as a coversoil material. When placed over subsoil (C), vegetation cover was significantly higher than when peat was placed over subsoil (BC/C) and subsoil (Bm1), which did not differ from each other (Figure 2.9). The subsoil material underlying the peat also had a significant effect on species richness (Table 2.3). Peat over subsoil (Bm1) had significantly higher richness than peat over subsoil (C) and subsoil (BC/C) (Figure 2.9). The underlying subsoil material also significantly affected community composition (Table 2.3); however, the difference appears to be driven by an unidentified *Carex* species that occurred in peat placed over subsoil (C) which peat over subsoil (BC/C) did not have. Communities on peat over subsoil (Bm1) did not differ from the communities found on peat placed over subsoil (C) or subsoil (BC/C).

2.4 Discussion

Coversoil material type mainly influenced composition and cover of colonizing vegetation in the first four years. Although tree species composition and cover can influence understory composition and cover in natural forests (Saetre et al. 1997, Pitkänen 2000, Macdonald and Fenniak 2007, Hart and Chen 2008), this study found that tree species selection and their planting density had little impact on the development of the unplanted vegetation community in the early developmental stage (<5 years). Additionally, despite some significant impacts of coversoil placement depth, total capping depth, and type of underlying subsoil material, they had little impact on early vegetation cover, richness, and community composition.

The finding that FFM had higher vegetation cover and richness as well as a plant community composed of species found in upland forests compared to the other coversoil materials was expected due to the putatively different propagule banks of the materials. As FFM was salvaged from an upland forest, the propagule bank likely contained species which are more suited to the drier conditions of upland areas, particularly for coarse textured soils (MacKenzie and Naeth 2010, Schott et al. 2016). Propagules contained within the peat material are likely of species adapted to the wetter conditions common in lowland areas (MacKenzie and Naeth 2010, Schott et al. 2016), and subsequently are not well suited to the drier conditions of upland sites. Additionally, the peat material was salvaged up to three meters deep; this would significantly dilute the propagules throughout the material as most propagules are found within the first 5-20cm of soil (Tacey and Glossop 1980, Putwain and Gillham 1990, Koch et al. 1996, Rokich et al. 2000, Zhang et al. 2001). The subsoil materials were also not anticipated to contain a large propagule bank due to the deeper salvage (Macdonald et al. 2015b).

Based on the indicator species analysis and the species lost and gained in the FFM between 2013 and 2015, there was a clear shift from a ruderal and annual forbs community to a perennial community with species such as naturally regenerated *Pinus banksiana* seedlings and *F. saximontana* (a small, upland grass species found in grass patches throughout the subregion). Although the developing plant community on FFM continued to contain annual forbs and graminoids in 2015, it also had several forest shrubs and native tree species. The NMDS revealed further that the community developing on FFM was characterized by native forest forb and shrub species such as *Epilobium angustifolium, V. myrtilloides* and *G. bicknellii*, while grasses and annual forb species dominated the peat and subsoil (Bm2 and C) coversoil treatments. The functional groups to which the indicator species belong is an important aspect of characterizing the plant communities as they potentially affect the successional trajectory of the reclamation sites. For example, shrubs have been found to act as a canopy by shading out ruderal species (Messier et al. 1998, Lieffers et al. 1999) which in turn can reduce competition and promote the development of forest understory species. Grasses on the other hand have been found to limit establishment and development of tree and understory species (Landhäusser et al. 1996, Hart and Chen 2006). The trajectory of the community developing on the FFM appears to follow the typical early successional progress of boreal forests from ruderal forbs and grasses to shrubs and trees.

The peat coversoil and subsoil treatments at the ASCS are not proceeding on the same trajectory as the FFM. Peat coversoil had significantly lower total vegetation cover over the first four years of monitoring (less than one percent in both 2013 and 2015). Other studies on early vegetation recovery on boreal forest reclamation sites have observed colonizing vegetation on a range of mixtures of peat and mineral soil rather than pure peat (used at the ASCS). Therefore results have been mixed with some studies finding lower cover values of early colonizing vegetation (MacKenzie and Naeth 2010), and others found cover well above 10% (Schott et al. 2016). While the difference between pure peat and peat mineral mixes has not been explicitly tested, the conditions in pure peat, as evident from this study, appear to be unfavourable to the establishment and development of colonizing vegetation from existing coversoil propagules and newly dispersed seed (see Chapter 3:).

The low cover in the peat treatments could be driven by a large range of variables such as nutrient availability, surface hydrophobicity, and/or lack of suitable microsites for propagules. For example, while not quantified, the pure peat surface was structurally homogenous with little micro topographical variation. Surface roughness and variability has been found to significantly increase natural aspen and forb establishment on reclamation sites with peat mineral mix as the coversoil (Schott et al. 2014, Pinno and Errington 2015); increased roughness results in longer seed retention time and access to moisture and nutrients (Johnson and Fryer 1992).

Interestingly, despite its overall low cover and diversity, total plant cover on the peat increased significantly in 2015 from 2013 while it decreased in the FFM and subsoil coversoil treatments. This increase is likely related to the ability of peat to maintain higher soil moisture conditions as a result of its organic matter content, which resulted in a positive response during the particularly dry year of 2015. These soil moisture conditions however were not sufficient to maintain the hydric conditions required by various lowland species that were observed on peat in 2013 but not again in 2015, including *Lobelia kalmii* and *Typha latifolia*. The increase of plant cover in the peat was mostly due to *Calamagrostis inexpansa* and *Salsola pestifer,* two species which were found in 2013 and became more prominent in the 2015 growing season. *Salsola pestifer* is an introduced and invasive tumbleweed most often found in disturbed rangelands in semi-arid habitats (Beckie and Francis 2009). As a C_4 species it is highly adapted to disturbed, dry, and potentially saline conditions (Beckie and Francis 2009), but is not anticipated to be a persistent species in the advanced plant communities on boreal forest reclamation sites. However, in dry years, as was the case in 2015, *S. pestifer* could thrive on the peat, an environment with little competition and challenging growing conditions. *Calamagrostis inexpansa* is a species of potential concern as it is a tall and aggressive rhizomatous grass closely related to *Calamagrostis canadensis*, one of the most prevalent and competitive native grass species in disturbed boreal forest areas (Lieffers and Macdonald 1993). The species uses vegetative reproduction, allowing it to quickly capture sites and outcompete native tree and other forest species (Macdonald and Lieffers 1993, Landhäusser et al. 1996). While *S. pestifer* is likely only a concern in the short-term until a canopy develops, *C. inexpansa* could be of greater concern in the future, as it has the potential to dominate a site in the long-term, reduce tree growth, and outcompete or inhibit the colonization of forest understory species.

With respect to total cover and richness, the treatments with no coversoil (e.g. only subsoil (Bm1) and subsoil (C)) performed similarly to peat, or in the case of species richness less than peat. While a no-coversoil treatment is currently not considered a standard practice in reclamation in Alberta, lack of coversoils is often a reality particularly towards the end of the life of mines. As these materials were salvaged from deeper soil horizons, they contain few viable propagules (Putwain and Gillham 1990, Macdonald et al. 2015b), and therefore likely rely heavily on outside sources for vegetation establishment. The low cover in the peat and subsoil coversoil treatments poses a potential risk of increased surface runoff, leading to erosion, particularly on slopes (Leatherdale et al. 2012). Coarse textured and high organic matter soils are also a risk to become hydrophobic during low soil-moisture conditions, which can further increase the risk of soil erosion (Hunter 2011, Leatherdale et al. 2012). Rapid vegetation development is desirable as it aids in soil stabilization and reduces soil erosion by intercepting precipitation (Carroll et al. 2000, Salazar et al. 2002).

The lack of a viable propagule bank in the peat and subsoil coversoil materials resulted in the poor early plant community development, lacking in cover and diversity. However, the plant community in these materials will most likely change as the site develops. Input of propagules that disperse from nearby forested areas or from older reclamation areas and areas that were capped with FFM could be propagule sources (Snively 2014; see also Chapter 3:). In time the coversoil materials will likely change chemically and physically which could improve establishment and growth. For example, canopy composition can have a significant influence on the understory vegetation community in forests as a result of litter fall and light availability that have an impact on environmental, physical, and chemical conditions (Hart and Chen 2006, Macdonald and Fenniak 2007). Broadleaf stands have more diverse understory vegetation communities than conifer or mixedwood stands as a result of the higher light transmission (Canham and Burbank 1994, Messier et al. 1998, 1999) and higher soil fertility as a result of litter decomposition (Paré and Bergeron 1996, Qian et al. 2003). As the tree seedlings begin to influence these conditions, germination of propagules that disperse into the peat and subsoil coversoils is anticipated to increase while the cover of early successional and ruderal species will decrease (Shropshire et al. 2001, DeGrandpré et al. 2003, Hart and Chen 2006).

Based on information collected in unmanaged and harvested stands (Carleton and Maycock 1981, Reich et al. 2001, Qian et al. 2003, Hart and Chen 2006), the cover and richness of the plant communities were expected to be greater in the planted aspen and mixed plots compared to the pine and spruce plots. However, the selection of planted tree species had generally no impact on total cover and richness to date. The only significant difference of tree species was for spruce and pine on the subsoil (C) treatment. As previously discussed, overall plant establishment on subsoil (C) sites was very low and this effect could have been an artifact as impacts of planted tree species were not observed in any of the other treatments. Most likely the impact of the planted tree species and the lack of a closed canopy muted the understory response during the early establishment phase. Only aspen reached a height greater than 1m and only when planted on FMM, all other seedlings were shorter with an overall average height of about 60cm (Bockstette unpublished). It can be expected that the effect of the tree seedlings will change in the future as they continue to grow and canopies close.

Tree density also affects the timing of canopy closure. Early signs of the canopy affecting understory vegetation cover were detected in 2015, where overall plant cover was lower in the FFM plots when planted at the higher seedling density. This may indicate that resources such as light are slowly becoming more limiting; however, planting density has not affected the colonizing vegetation community composition to date. As the canopy develops, a shift from competitive, resource demanding and mostly shade intolerant species (i.e. *E. angustifolium, Calamagrostis* sp., and *R. idaeus*), to less competitive but shade tolerant species (i.e. *Linnaea borealis, Cornus canadensis*), is anticipated (Lieffers and Stadt 1994, Shropshire et al. 2001, DeGrandpré et al. 2003, Økland et al. 2003, Hart and Chen 2006).

Although germination and establishment of propagules can be affected by the amount of surface material applied (Holmes 2001, MacKenzie and Naeth 2010, Landhäusser et al. 2015, Macdonald et al. 2015b), the average density of propagules per unit of soil in the viable germination zone should be similar in both the shallow and deep applications. As a result, initial cover and richness was anticipated to be similar between the two application depth treatments for both FFM and peat. The similar responses in the 10 and 20cm FFM treatments could also be due to the issues encountered when establishing the 10cm application for the study sites. The coarse woody debris in the FFM made it difficult to achieve a 10cm placement depth; post soil placement depth checks for the 10cm FFM coversoil treatment plots showed an average material depth of 14cm (M. Yarmuch personal communication). Therefore, the placement depth difference for the FFM treatments may not have been large enough for this test. Regardless, studies have found emergence from propagules decreases with burial depth (Tacey and Glossop 1980, Putwain and Gillham 1990, Grant et al. 1996, Rokich et al. 2000, Landhäusser et al. 2015); therefore, as coversoil material placement depths thicken, there is an increased probability that buried propagules will not be able to emerge. However, application depths needs to be balanced with the survival of the propagules as too shallow of an application could result in a desiccation of the propagules (Wachowski et al. 2013; Landhäusser et al. 2015). Although total cover in both the deep and shallow applications of the peat coversoil material was very low, the plant cover in the deeper application was greater. It appears that this higher cover could be related to the higher soil water retention in the deeper peat treatment during the dry growing season of 2015. This is supported by the similarity of plant communities between the two treatments; the greater water availability in the deeper peat treatment simply might have resulted in greater plant productivity.

While vegetation propagules are found in the coversoil (Paré et al. 1993, Schimmel and Granström 1996, Greene et al. 1999, MacKenzie and Naeth 2010, Macdonald et al. 2015b), the expression and early development of that propagule bank appears to also be influenced by the underlying materials. Nutrient status of the subsoil material could have played a role as the treatments with subsoil (Bm1) had the highest species richness and this material had significantly higher concentrations of phosphorous than the other two subsoils. The benefit of the buried subsoil (Bm1) was also evident in the growth of the planted aspen seedlings, as those planted over the subsoil (Bm1) had the highest growth in the first three growing seasons (Bockstette unpublished).

Unlike other studies where areas were treated with a broadcast fertilizer (Norman et al. 2006, Schott et al. 2016), no increases in cover by nitrophilous and graminoid species were observed in the FFM treatment with higher phosphorous availability as a result of the underlying subsoil (Bm1). While the FFM over subsoil (Bm1) treatment had various grasses (*A. scabra*, *Agropyron trachycaulum* var *unilateral*) and annual herbaceous species (*Chenopodium album*, *Sonchus* sp.), it also contained several forest species (e.g. *Betula papyrifera, Linnaea borealis, Maianthemum canadensis*, etc.). Despite the increased graminoid richness in the treatment, it appears that competition pressure from these species has not played a role at this stage in the forest understory species development, as no reduction in the overall species richness was observed (Landhäusser et al. 1996, Hart and Chen 2008, Skousen et al. 2009, Schott et al. 2016).

Total capping depth had little impact on the overall early development of the plant community, likely as a result of all treatments having 30cm of peat coversoil and only varied in the thickness of the subsoil (BC/C) layer. Regardless, of the different subsoil (BC/C) placement depths of these treatments, the vegetation cover was low for all the treatments; however, species richness was highest in the shallow total capping depths (30 and 60cm). The difference in species richness is not easily explained and could be an artifact; however, the overall lack of a vegetation response to the total capping material depth treatments might be the result of the poor colonization and performance on the peat coversoil which did not allow plants to fully occupy the soil column with their root systems. As vegetation matures and root systems develop further down the soil profile, the impact of subsoil on understory development may become more important.

2.5 Conclusions

The main driver that determines the early trajectory of colonizing vegetation community development in upland forest reclamation is the type of coversoil material used. The propagule banks contained within FFM, peat, subsoil (Bm2), and subsoil (C) resulted in different vegetation communities, with FFM producing the most productive and diverse community. Development of the vegetation community using FFM also appears to be moving plant communities on a trajectory that more closely resembles upland forest types with forbs, shrubs, and trees common to forests emerging from the material. At this early stage, plant communities on peat, subsoil (Bm2), and subsoil (C) appear to be on a different trajectory; however, the peat material appears to modulate water availability, which benefits plants during times of dry conditions.

At this early stage in vegetation development the selection of trees species had little to no impact on the vegetation community. However, planting at the higher density reduced plant cover on FFM, likely a result of reduced light availability from increased canopy cover. The intended result of planting at a higher density to shade out grass and ruderal species (e.g initiate a change in community type) has not yet occurred. As the tree seedlings become larger and a more dominant feature of the reclaimed landscape, their effect on the vegetation community is anticipated to become more significant.

Soil placement depth and the type and arrangement of subsoils also had some impact on the development of vegetation communities in both FFM and peat early on. Seedbed characteristics and nutrient availability seem to be affected by the placement depth and arrangement of soil materials. However, these differences are not yet clear and will likely manifest themselves in future years when root systems begin to occupy a larger volume of the soil column.

Tables

Table 2.1: Summary of physical and chemical properties of the soil material types. Values represent means and standard deviations. Means with a different letter indicate a significant difference between treatments. Note: 'DBD' refers to dry bulk density, 'EC' refers to electrical conductivity, 'SAR' refers to sodium adsorption ratio, 'OM' refers to organic matter, 'TOC' refers to total organic carbon, 'TON' refers to total organic nitrogen, and 'NM' refers to not measured.

		Peat	FFM	Subsoil (Bm1)	Subsoil (BC/C)	Subsoil (Bm2)	Subsoil (C)	LOS
Capping Depth (cm)		10 / 30	10 / 20	30	30-130	150	90-150	NM
Salvage Depth (cm)		0-300	0-15	15-50	50-100	15-50	15-250	NM
Particle Size Distribution (%)	Sand	NM	91.6 **b** (1.2)	93.2 **ab** (0.38)	94.7 **a** (0.3)	93.2 **ab** (1.4)	94.7 **a** (1.3)	59.0 **c** (1.7)
	Silt	NM	4.0 **b** (0.89)	2.6 **ab** (0.46)	1.2 **c** (0.18)	2.3 **ab** (1.0)	1.9 **ab** (0.8)	28.7 **a** (1.3)
	Clay	NM	4.4 **b** (0.32)	4.3 **b** (0.25)	4.2 **b** (0.22)	4.5 **b** (0.63)	3.6 **b** (0.5)	12.3 **a** (0.39)
DBD ($g \cdot cm^{-3}$)		0.6 **a** (0.04)	1.1 **b** (0.06)	1.6 **c** (0.05)	1.7 **d** (0.04)	1.7 **d** (0.03)	1.5 **d** (0.02)	1.6 **cd** (0.03)
Bitumen (%)		NM	NM	NM	NM	NM	NM	2.7 (0.18)
pH		7.4 **bc** (0.06)	5.6 **e** (0.22)	6.0 **e** (0.28)	7.3 **c** (0.08)	8.0 **a** (0.08)	6.8 **d** (0.2)	7.7 a**b** (0.01)
EC ($dS \cdot m^{-1}$)		1.2 **b** (0.11)	0.2 **c** (0.04)	0.2 **c** (0.02)	0.3 **c** (0.03)	0.3 **c** (0.03)	0.2 **c** (0.04)	2.4 **a** (0.1)
SAR		0.56 **b** (0.07)	0.20 **b** (0.01)	0.21 **b** (0.01)	0.30 **b** (0.05)	0.13 **b** (0.03)	0.32 **b** (0.06)	5.3 **a** (0.63)
OM (%)		34.1 **a** (2.6)	2.6 **b** (0.5)	NM	NM	0.98 **b** (0.38)	0.77 **b** (0.31)	NM
TOC (%)		17.0 **a** (1.3)	1.3 **b** (0.25)	NM	NM	0.49 **b** (0.19)	0.38 **b** (0.16)	NM
TON (%)		0.74 **a** (0.04)	0.04 **b** (0.01)	NM	NM	0.02 **b** (0.0)	0.02 **b** (0.0)	NM
Available nutrients ($mg\ kg^{-1}$)	NO_3^-	12.4 **a** (2.5)	2.0 **b** (0.0)	2.3 **b** (0.38)	2.0 **b** (0.0)	2.0 **b** (0.0)	2.0 **b** (0.0)	NM
	NH_4^+	1.3 **ab** (0.05)	2.2 **a** (1.1)	0.34 **b** (0.04)	0.3 **b** (0.0)	0.31 **b** (0.01)	0.37 **b** (0.05)	NM
	P	5.0 **c** (0.0)	24.6 **a** (0.39)	27.6 **a** (4.6)	10.8 **b** (0.95)	5.04 **c** (0.07)	9.4 **bc** (2.1)	NM
	K^+	35.6 **a** (0.82)	41.2 **a** (7.6)	26.5 **b** (2.7)	24.8 **b** (0.98)	25.04 **b** (0.07)	24.4 **b** (0.62)	11.2 * (4.5)
	SO_4^-	482 **a** (149)	5.0 **b** (0.56)	2.7 **b** (0.79)	4.0 **b** (0.92)	2.04 **b** (0.31)	4.5 **b** (3.9)	207 * (118)

*Values not included in analysis comparing the available nutrients between the substrates

Table 2.2: Results of linear mixed effects model ANOVAs for total vegetation cover and total species richness and the perMANOVA on the vegetation cover community for Model 1 (n=3). Note: ‘Y’ represents year, ‘CM’ represents coversoil material, and ‘TS’ represents planted tree species.

	Total Cover	Total Species Richness	Cover Community
Year (Y)	0.823	0.394	**0.017**
Coversoil material (CM)	**<0.001**	**<0.001**	**<0.001**
Y × CM	**<0.001**	0.101	**0.006**
Tree species planted (TS)	0.444	**0.001**	0.247
Y × TS	0.735	0.894	0.738
CM × TS	0.761	**<0.001**	0.230
Y × CM × TS	0.721	0.958	0.973

Table 2.3: Results of permANOVAs on total vegetation cover and total species richness, and the perMANOVAs on the vegetation cover community for Model 2 (n=3). Note: ‘TS’ represents tree species, ‘PD’ represents planting density, ‘SD’ represents coversoil depth, ‘CD’ represents capping depth, and ‘ST’ represents subsoil material type.

	Total Cover		Total Species Richness		Vegetation Cover Community	
	FFM	Peat	FFM	Peat	FFM	Peat
Tree Species (TS)	0.170	1.00	0.296	0.150	0.831	0.429
Planting Density (PD)	**<0.001**	0.441	0.114	0.433	0.120	0.124
TS x PD	0.360	0.323	0.213	0.435	0.520	0.473
Coversoil Depth (SD)	0.594	**0.002**	0.563	0.242	0.205	**<0.001**
Tree Species (TS)	0.239	0.212	0.800	0.154	0.567	0.119
SD x TS	0.329	0.390	0.808	0.557	0.579	0.711
Capping Depth (CD)	-	0.182	-	**<0.001**	-	0.646
Tree Species (TS)	-	0.483	-	0.200	-	**0.030**
CD x TS	-	0.379	-	0.253	-	0.305
Subsoil Material Type (ST)	**0.001**	**<0.001**	**<0.001**	**0.004**	**<0.001**	**0.001**
Tree Species (TS)	0.727	0.349	0.146	0.255	0.558	**0.012**
ST x TS	0.535	0.325	0.381	0.227	0.361	0.871

Figures

Figure 2.1: Map of the Aurora Soil Capping Study (ASCS). The soil layering treatment (Figure 2.2) is designated in each cell within circles and tree plots are designated as squares with their planting treatment identified within. Tree plots that were planted at low densities (2,000sph) rather than high densities (10,000sph) are designated with a subscript 2. Note: 'A' refers to trembling aspen, 'S' refers to white spruce, 'P' refers to jack pine, and 'M' refers to mixed tree plots.

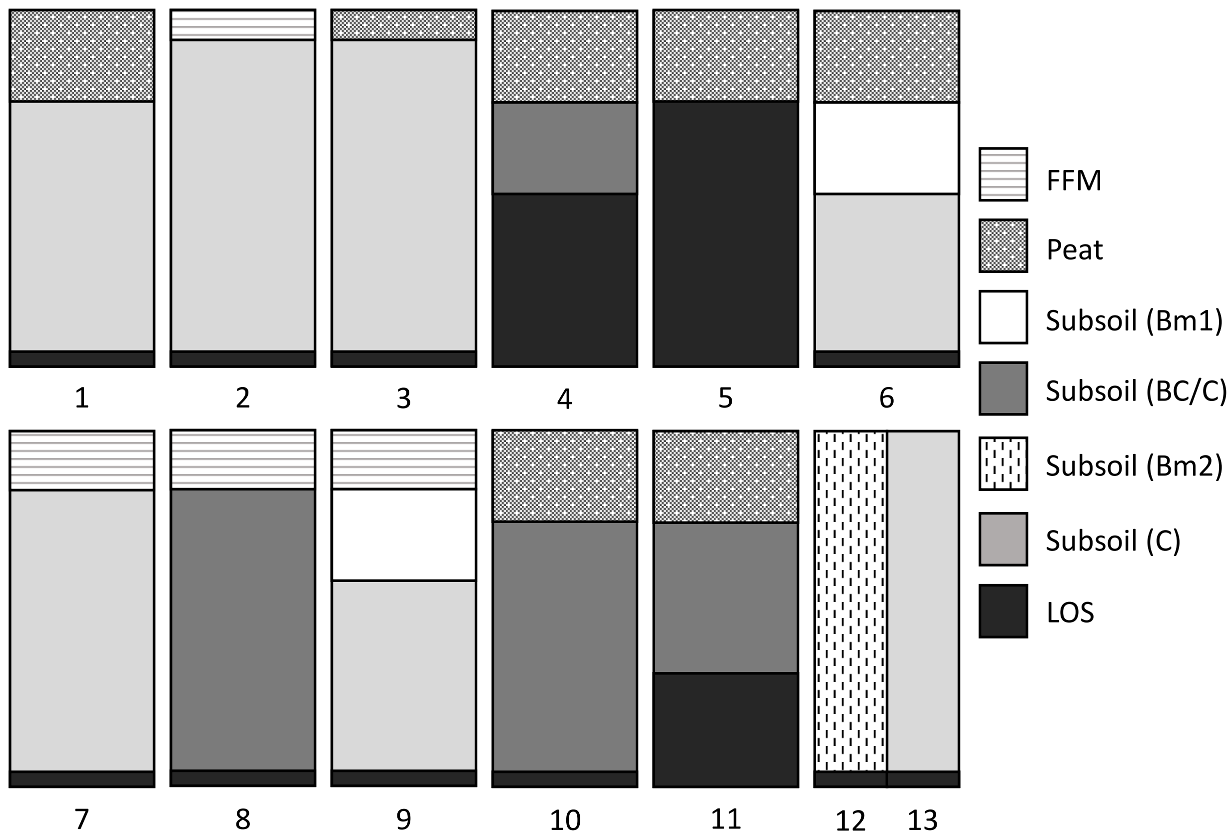


Figure 2.2: The 13 soil layering treatments at the Aurora Soil Capping Study (ASCS). Treatment 1 is 30cm of peat over 120cm of subsoil (C). Treatment 2 is 10cm of forest floor material (FFM) over 140cm of subsoil (C). Treatment 3 is 10cm of peat over 140cm of subsoil (C). Treatment 4 is 30cm of peat over 30cm of subsoil (BC/C). Treatment 5 is 30cm of peat. Treatment 6 is 30cm of peat over 30cm of subsoil (Bm1) over 90cm of subsoil (C). Treatment 7 is 20cm of FFM over 130cm of subsoil (C). Treatment 8 is 20cm of FFM over 130cm of subsoil (BC/C). Treatment 9 is 20cm of FFM over 30cm of subsoil (Bm1) over 100cm of subsoil (C). Treatment 10 is 30cm of peat over 120cm of subsoil (BC/C). Treatment 11 is 30cm of peat over 70 cm of subsoil (BC/C). Treatment 12 is 150cm of subsoil (Bm2) and Treatment 13 is 150cm of subsoil (C). All of these treatments were placed over lean oil sands (LOS) overburden material. Physical and chemical characteristics of these materials can be found in Table 2.1.

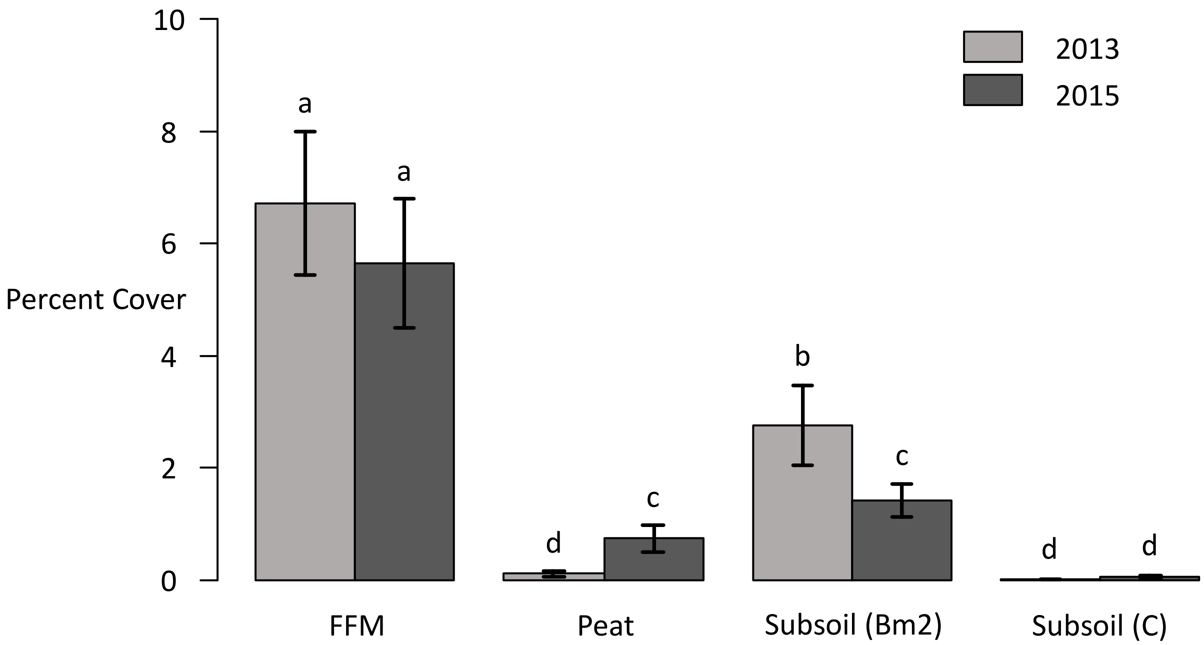


Figure 2.3: Average total vegetation percent cover for the four coversoil material types (FFM, peat, subsoil (Bm2) and subsoil (C)) in the 2013 and 2015 growing seasons. Bars indicate standard errors of the mean and lowercase letters indicate significant differences between the averages. Light gray bars indicate the 2013 averages and dark greys bars indicate the 2015 averages.

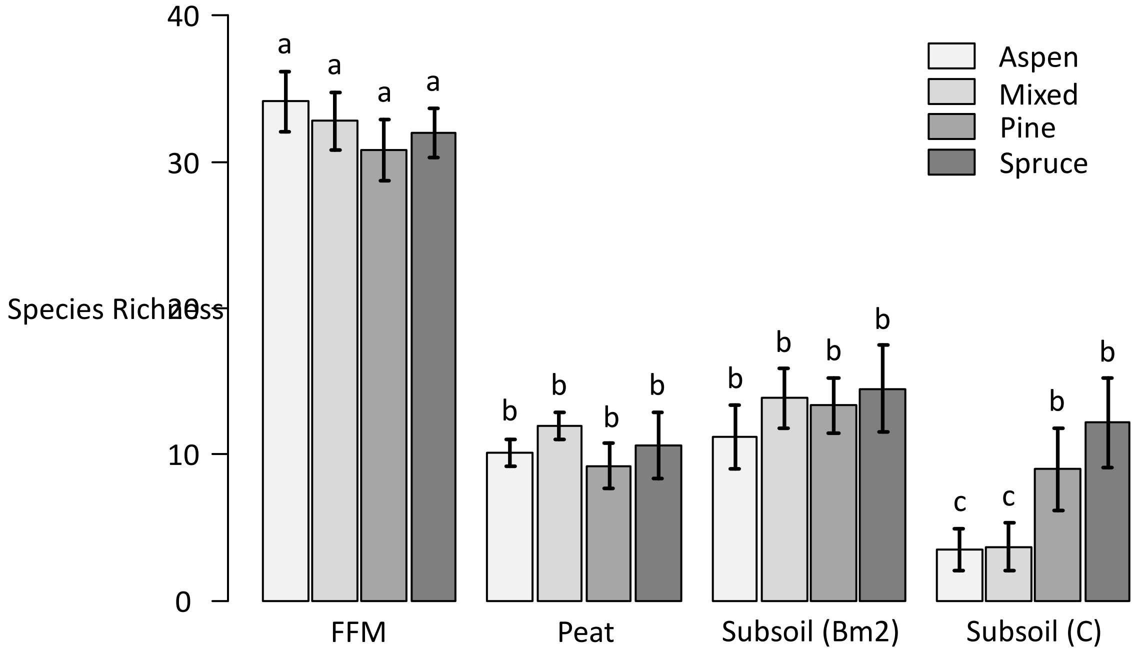


Figure 2.4: Average total species richness for each of the planted tree species plots per coversoil material type (2013 and 2015 growing season data averaged). Bars indicate standard errors of the mean and lowercase letters indicate significant differences between the averages.

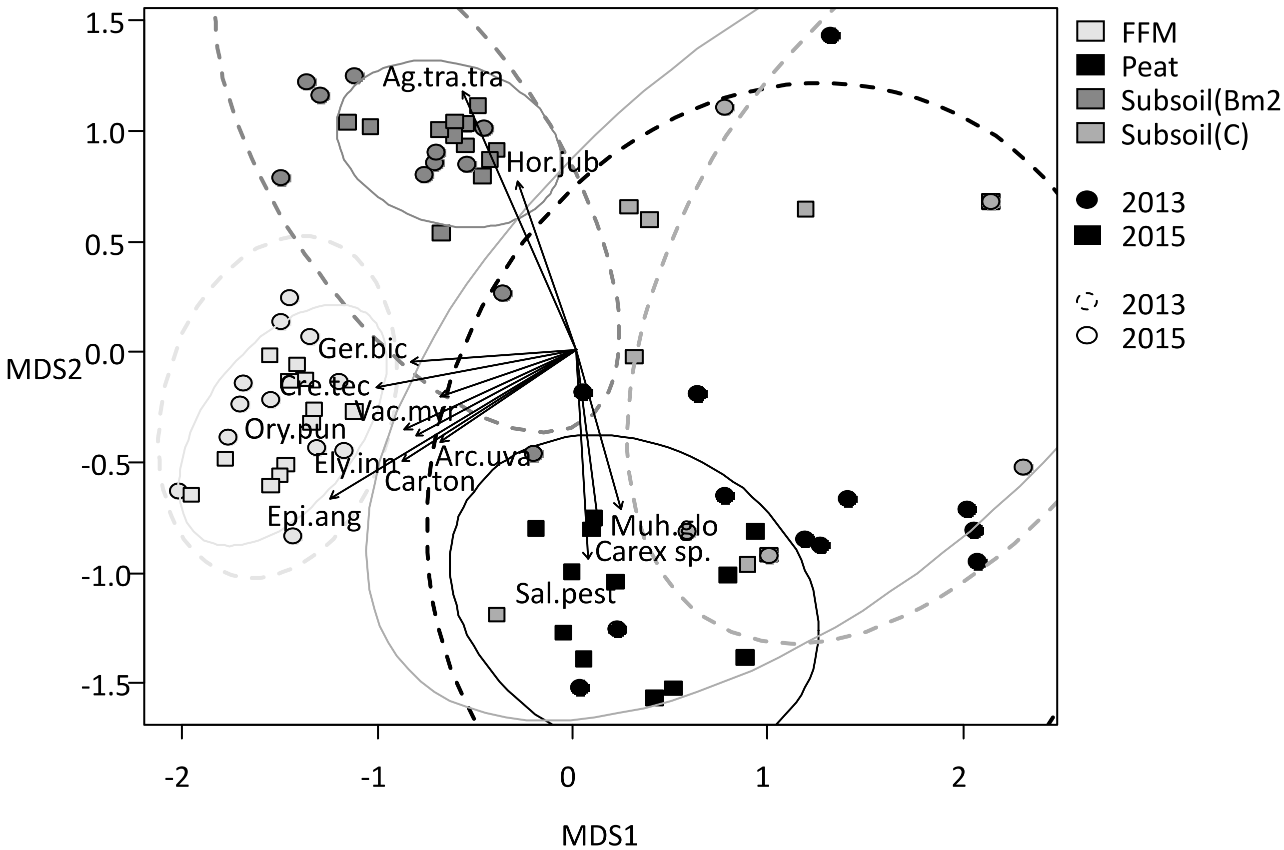


Figure 2.5: Results of an NMDS ordination made for the 2013 and 2015 vegetation cover community composition in each of the four coversoil materials (stress=0.151). The colour shading represents a plot in each of the coversoil materials (light grey=FFM, black=peat, dark grey=subsoil (Bm2), medium grey=subsoil (C)). The point shapes represent the year that the plot was sampled in (circle=2013 and square=2015). Ellipses delineate a 95% confidence interval around the centroid of the different coversoil materials for the different years (dashed line=2013 and solid line=2015). The arrows represent a selection of species that had a significant species score ($\alpha \leq 0.002$). Not all species with this significant species score were shown to allow for legibility in the figure; the entire list of species with the significant species score can be found in Appendix A.V.

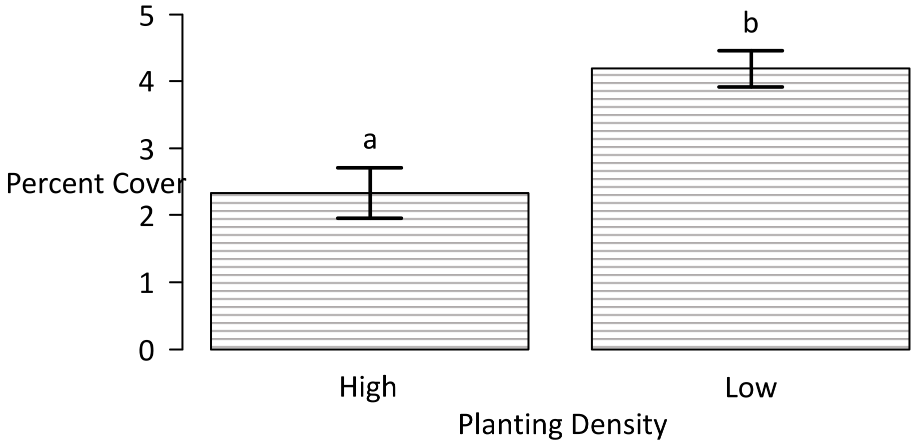


Figure 2.6: Average vegetation cover of the two planting densities (10,000 & 2000sph) in FFM (treatment 8) in the 2015 growing season. Bars indicate standard errors of the mean and lowercase letters indicate significant differences between the averages.

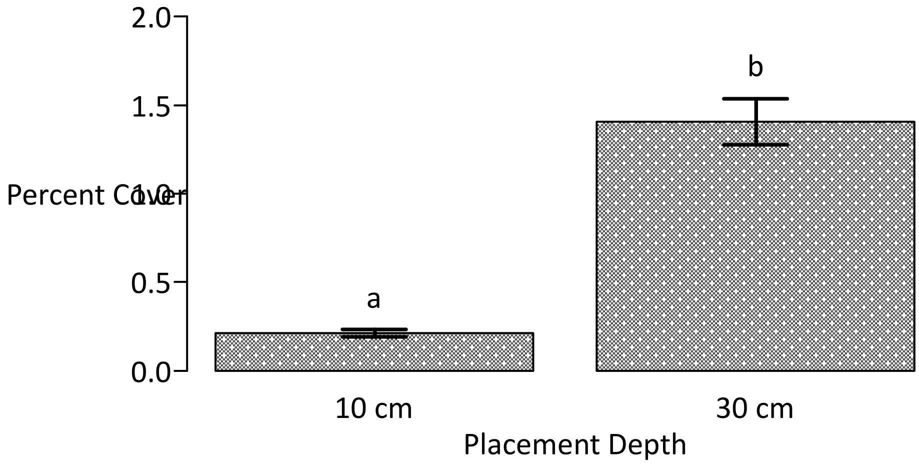


Figure 2.7: Average vegetation cover of the two peat placement depths (10 & 30cm) in the 2015 growing season. Bars indicate standard errors of the mean and lowercase letters indicate significant differences between the averages.

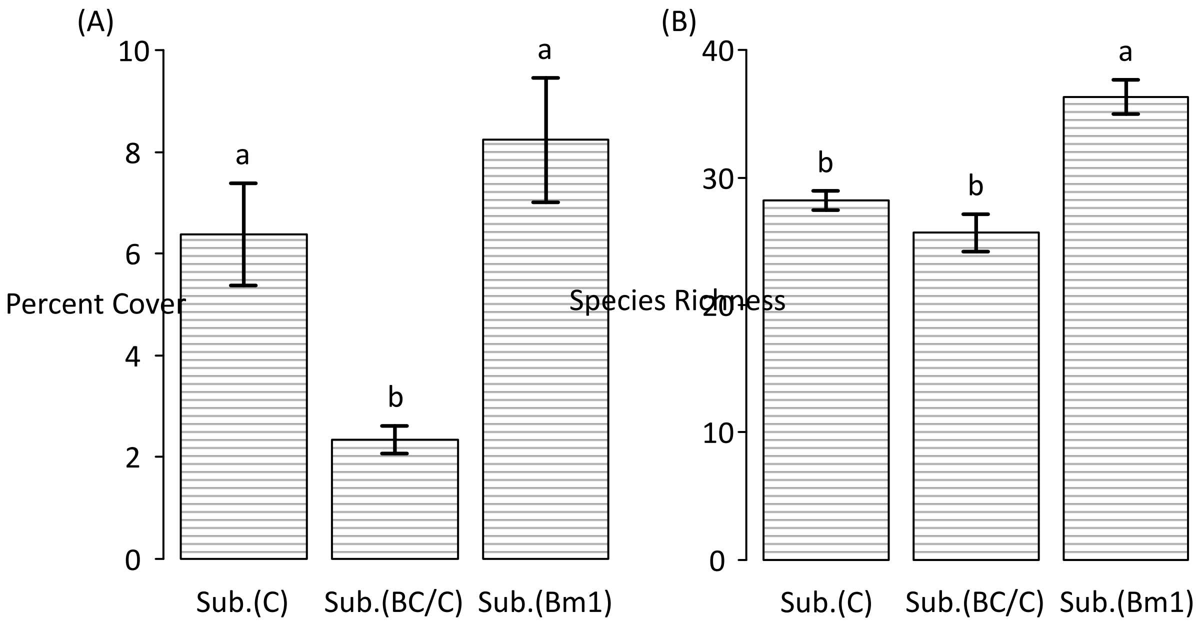


Figure 2.8: Average vegetation cover (A) and species richness (B) of the three subsoil treatments (subsoil (C), subsoil (BC/C), subsoil (Bm1) over subsoil (C)) overlain by 20cm of FFM in the 2015 growing season. Bars indicate standard errors of the mean and lowercase letters indicate significant differences between the averages.

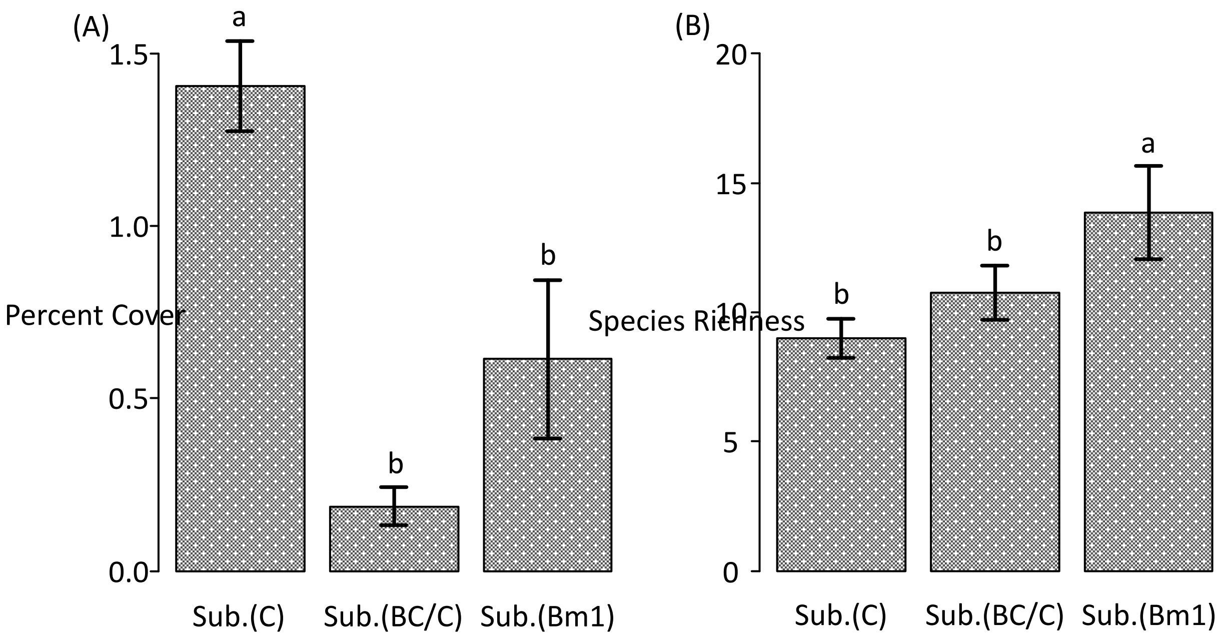


Figure 2.9: Average vegetation cover (A) and species richness (B) of the three subsoil treatments (subsoil (C), subsoil (BC/C), subsoil (Bm1) over subsoil (C)) under 30cm of peat in the 2015 growing season. Bars indicate standard errors of the mean and lowercase letters indicate significant differences between the averages.

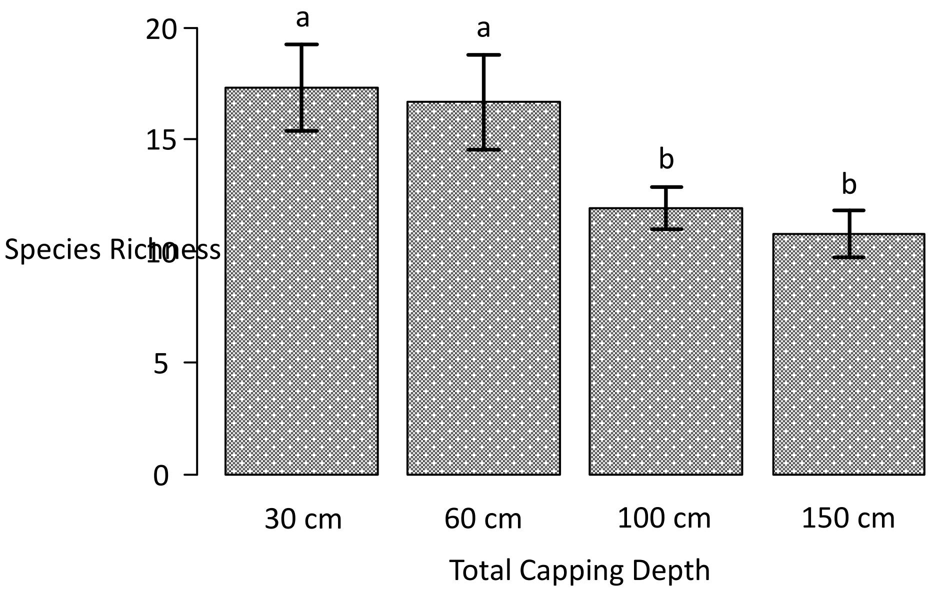


Figure 2.10: Average species richness of the four capping depths (30, 60, 100 and 150cm; all include 30cm of peat as the coversoil material) in the 2015 growing season. Bars indicate standard errors of the mean and lowercase letters indicate significant differences between the averages.

Chapter 3: Vegetation dispersal from forest floor material islands: applying a nucleation strategy in upland forest reclamation

3.1 Introduction

As a result of large scale resource extraction operations, forest reclamation has become an increasingly common practice in the Canadian boreal forest. Reclamation often aims to return areas disturbed by these operations back to functioning ecosystems with equivalent land capabilities (Powter et al. 2012). Vegetation contributes to a variety of ecosystem functions including soil stabilization, nutrient cycling, water filtration, and food and pollen sources (Carroll et al. 2000, Nilsson and Wardle 2005, Gilliam 2007; see Table 1.1), and as such the re-establishment of plant communities on reclamation sites is critical.

Seeding and planting of native plant species is one method available for reclamation practitioners to re-introduce a range of plants on reclaimed landscapes; however, these are often costly operations that require commercially available seed sources (Macdonald et al. 2012). Alternatively, vegetation can be introduced onto a reclamation site either from nearby seed sources or from propagule banks contained in salvaged forest soils (Koch et al. 1996, Holmes 2001, Holl 2002). For upland reclamation directly placed soil salvaged from forests (e.g. salvaged material with no storage time between salvage and reclamation placement) has been found to result in more productive and diverse plant communities than directly placed soils salvaged from lowland areas (MacKenzie and Naeth 2010, Schott et al. 2016); however, in many parts of the boreal forest lowland soils dominate, limiting the amount of salvable upland soils for reclamation (Fung and Macyk 2000, Macdonald et al. 2012). Therefore, salvaged upland forest soil material needs to be used strategically in order to maximize its effectiveness at establishing forest plant communities within reclaimed landscapes.

An alternate revegetation method to seeding/planting is using a restoration technique that involves establishing patches of vegetation that can then attract dispersal agents and act as central areas for plant species to spread from, referred to as applied nucleation (Robinson and Handel 2000, Corbin and Holl 2012, Boanares and Azevedo 2014). While there are a variety of applied nucleation strategies (see Reis et al. 2010, Boanares and Azevedo 2014), one method which has been proposed in boreal forest reclamation is the placement of salvaged upland forest soil in islands throughout reclaimed landscapes (Sturgess and Atkinson 1993, Alberta Environment and Water 2011, Naeth et al. 2013). These islands are anticipated to allow native species contained within the forest floor propagule bank to establish and then spread into the adjacent reclamation materials (Alberta Environment and Water 2011, Naeth et al. 2013). While egress of species from forest floor soil material (FFM) into regions capped with soil salvaged from lowland areas (peat) has been documented anecdotally (Naeth et al. 2013, Snively 2014), little work has focused on determining how quickly the dispersal occurs and which dispersal mechanisms are the most dominant and effective. Additionally, while some work has examined the type of species capable of contributing to this egress (Robinson and Handel 2000, Winterhalder 2004, Corbin et al. 2016), the assessment of the migrating community as a whole has received little attention.

To disperse, plants can use sexually derived propagules such as seeds or spores and/or asexually derived propagules such as rhizomes, bulbils, and root suckers. Seed propagules must disperse far enough away from the mother plant to limit intra-specific competition (Grime 2001). There are two phases and two main types of seed dispersal. The first dispersal phase refers to the time it takes for a seed to reach the ground from the mother plant while the second phase is any vertical or horizontal movement by the seed once it reaches the surface (Chambers and MacMahon 1994). Dispersal via autochory includes any seed transport using gravity or active dispersal by the plants such as a ballistic or self-propelling mechanisms, while allochory includes more varied dispersal mechanisms such as wind, water, and biotic transport (Chambers and MacMahon 1994, Bakker et al. 1996). Within the boreal forest most species which utilize seeds rely on wind or biotic dispersal mechanisms (Matlack 1994).

The distance seeds disperse by wind typically follows a decay curve with the majority of seeds falling closer to the mother plant (Harper 1977, van der Valk 1992). The dispersal distance depends on a variety of factors, including wind speed, release height, and the surrounding vegetation (Augspurger and Franson 1987, Cadenasso and Pickett 2001). Biotic dispersal includes seed vectored by animals, such as birds, mammals, and ants (Chambers and MacMahon 1994). Morphological adaptations of seeds have developed to increase dispersal distance by both wind (wings, plumose appendages, pappus, etc.) and biotic (barbs, hooks, colourful seed coats, etc.) vectors (Howe and Smallwood 1982, Matlack 1987, Chambers and MacMahon 1994). Active and passive human transport is also considered a biotic dispersal mechanism and is primarily attributed to soil movement and phytoculture (Hodkinson and Thompson 1997).

Vegetative expansion through asexual reproduction is most frequently present in habitats where disturbances are common (Grime 2001). The boreal forest is shaped by frequent fires, and as a result the regeneration of many species through rhizomes, root and basal sprouts, and stolons is very common (Rowe 1956, Roberts 2004, Hart and Chen 2006). Like seed dispersal, there are a variety of factors that influence vegetative expansion. Below ground vegetative reproductive structures are affected by soil bulk density, soil moisture, nutrient availability, soil pH, soil temperature and texture, as well as the health and rigor of the mother plant as influenced by climatic conditions (Landhäusser and Lieffers 1999, Frey et al. 2003).

This research aims to identify species that colonize reclamation areas adjacent to large FFM islands and explore the mechanisms that facilitate these species to migrate. Species which utilize seeds, particularly those that are adapted for wind dispersal, are anticipated to migrate the greatest distances from the islands. However, as many herbaceous species in the boreal forest utilize vegetative reproduction, a greater proportion of the vegetation community in the transition zone neighbouring the islands is expected to be occupied by species which utilize rhizomes, root sprouts, and stolons for dispersal. To test the dispersal of species out of FFM islands, seed rain and egress of vegetation into peat material adjacent to FFM islands were examined in the third and fourth growing season at an upland boreal forest reclamation site.

3.2 Methods

3.2.1 Research Area

Research for this project took place at the Aurora Soil Capping Study (ASCS), which is a large-scale reclamation experiment (36ha) located at the Syncrude Aurora North Mine (57°20'01.2"N, 111°31'58.2"W). The Aurora North Mine is located approximately 80km north of Fort McMurray, Alberta, Canada, and is one of two active oil sand open-pit mines held by Syncrude Canada Ltd (Syncrude Canada Ltd 2015). Syncrude's mines are located within the

Alberta central mixedwood natural subregion, an area made up of a mosaic of upland and lowland sites. Upland forests are typically either mixedwood stands of White spruce (*Picea glauca* Moench.) and Trembling aspen (*P. tremuloides*) on fine textured Luvisolic soils or Jack pine (*Pinus banksiana* Lamb.) stands on coarse textured Brunisolic soils (Soil Classification Working Group 1998, Natural Regions Committee 2006). Lowland sites are typically either fens or bogs dominated by Black spruce (*Picea mariana* Mill.) that have developed on poorly drained Organic soils (Soil Classification Working Group 1998, Natural Regions Committee 2006).

In the 2013 growing season (May to September) the average daily temperature at the ASCS was 16.0^{o}C and rainfall totalled 318.6mm. The average daily wind speed during the growing season was 3.1m s^{-1} and the prevailing wind was from the southeast. During the dormant season (October 2013 to April 2014) average daily temperature was -10.4^{o}C. The 2014 growing season had an average daily temperature of 14.5^{o}C with 343.1mm of total rainfall. During this time the average daily wind speed was 2.78m s^{-1} with wind again primarily coming from the southeast. The following dormant season had an average temperature of -9.6^{o}C. In the 2015 growing season the daily average temperature was 14.8^{o}C and total rainfall was 208.0mm. Average daily wind speed was 2.63m s^{-1} and average wind direction was from the south.

3.2.2 Site Construction

The ASCS was built on a lean oil sand (LOS) overburden dump and was designed as a large collaborative study to test reclamation questions related to appropriate capping prescriptions over LOS material. The LOS material had a sandy loam texture, a neutral pH, and an average bitumen content of 2.7% by weight. The ASCS is composed of 36, one-hectare treatment cells that have a range of coversoil and subsoil materials. The study incorporated two coversoils: peat and FFM, and four subsoils: two types of Bm, BC/C, and C horizons. Cells were set up in rows (North-South) with small paths or gullies separating them (East-West). For the purpose of this research only the peat and FFM treatments are relevant, with FFM cells acting as the FFM islands.

The peat coversoil material was salvaged from a lowland area within the mine footprint to a maximum depth of approximately three meters and was directly placed on the site as a coversoil material. The material was 34% organic matter by weight. Forest floor coversoil material (FFM) was salvaged from an upland forested area dominated by Jack pine (*P. banksiana*) which developed on predominantly sand textured Brunisolic soils. This material was salvaged to a depth of approximately 15cm to capture the forest litter layers (LFH), the underlying A horizon, and potentially a portion of the B horizons; the FFM was also directly placed on the ASCS. Soil placement was complete prior to the 2012 growing season. In May 2012 planting of native tree (trembling aspen, jack pine and white spruce) seedlings in tree plots within the one-hectare cells occurred. Outside of the tree plots within each cell native shrubs (Pincherry (*Prunus pensylvanica* L.f.), Green alder (*Alnus crispa* Chaix.), and Saskatoon (*Amelanchier alnifolia* (Nutt.) Nutt. ex M. Roem.)), and additional tree seedlings were also planted. More details on the ASCS study and design can be found in Chapter 2:.

3.2.3 Vegetation Measurements

Species composition of the FFM islands, excluding the planted species, were assessed in July 2013and 2015 using walkthroughs of the tree plots centered within each island. All species present within the tree plots were identified. The 2013 species composition in the FFM islands (see Chapter 2:) was used to determine a baseline of FFM species.

To assess plant community composition, three belt transects (2m x 30m each) were established along eleven clearly discernible borders separating the FFM islands from the surrounding peat material (Figure 3.1). Belt transects were initiated approximately five meters inside the FFM and extended to 25m perpendicular to the FFM-peat border into the peat material. In each belt transect vegetation was evaluated by percent cover and presence/absence by species (excluding planted trees and shrubs). Percent cover was assessed in six sampling quadrats (1.43m x 1.43m) located immediately adjacent to the border in the FFM and in the peat as well as at 5, 10, 15, and 20m from the border in the peat material. Within each quadrat, individual species were identified and their percent cover visually estimated. Cover was estimated to the nearest 1%; if less than 1%, cover was either determined to be 0.5% or trace (0.001%). Cover estimates were done by a single researcher to ensure consistency and Coroplast cut-outs of 1% and 5% were used to help estimate cover more accurately. Presence/absence was also assessed along each belt transect; however, unlike percent cover, presence/absence was observed for the entire transect. The location of each plant that occurred within the belt transect was recorded to the nearest 10cm from the border. The measurements from the three transects were averaged prior to analysis to provide data for a single transect for each border.

Sampling of the belt transects was done on July 16-21, 2014 and July 8-12, 2015. Whenever possible, vegetation was identified to species in the field; otherwise the specimens were collected and identified later in the lab. All scientific species nomenclature is based on Flora of Alberta (Moss 1994) and a full list of all species identified in the belt transects is presented in Appendix B.I.

3.2.4 Seed Rain Collection

Across four of the borders used for the belt transects, seed trap transects were established prior to the 2014 growing season. Seed traps were set up five meters inside the FFM island, on the border between the FFM and the peat, and 10 and 20m from the border in the peat material (Figure 3.1). Funnel and adhesive seed traps were used at each collection location. Adhesive traps collect wind dispersed seeds while funnel traps typically collect seeds dispersed by wind and gravity (Chabrerie and Alard 2005). Both types were installed adjacent to one another without interfering with each other.

Funnel seed traps were constructed by inserting a plastic funnel (8” diameter) into an Elite® 600 Nursery Container by ITML Horticultural Products Inc. (8.5” diameter and height, produced in Brantford, Ontario, Canada) (Figure 3.2A). Nylon stockings were taped to the bottom of the funnels to capture seeds. Nylon stockings and the Elite® 600 pots were selected as they facilitate good drainage in the seed traps through the mesh and pre-existing drainage holes. The funnel traps were installed level with the soil surface (Chabrerie and Alard 2005).

Adhesive traps were built by affixing a Coroplast plate (30cm x 30cm) to a wooden frame with large binder clips (Figure 3.2B). These plates were covered in a layer of Bag Balm® (a grease product originally produced to prevent chaffing of cow udders, made by Vermont’s Original in Lyndonville, Vermont, USA). This sticky material has been found to maintain its adhesive qualities even after prolonged exposure to field conditions (Chabrerie and Alard 2005). The wooden frame was constructed out of a plywood plate affixed to a wooden stake at a 45° angle (Chabrerie and Alard 2005). Seed trap frames were installed at the reclamation site approximately 10-15cm above the soil surface.

Funnel seed traps were installed on May 9, 2014 and adhesive traps were installed on May 31, 2014 (frozen soil prevented earlier installation). Both periods were well before the seed dispersal of species in the region. Samples from the seed traps were collected monthly between May and October. When the funnel traps were collected, the funnel was removed from the pot, the nylon stocking detached and replaced with a new one, and the funnel was then reattached to the pot and placed back in the soil. The nylon stocking (often containing soil, twigs, blown in leaves, etc.) was placed into a labeled paper bag. Adhesive trap samples were collected by removing the Coroplast from the wooden stand, wrapping it in saranwrap and placing it in a labeled Ziploc® bag. New Coroplast sheets were then placed on the wooden frame and fresh Bag Balm® applied.

The content of each funnel trap nylon stocking was weighed, well mixed, and then split into two equal parts. These were then randomly assigned to be immediately germinated or frozen at -20°C for at least seven months and then germinated. The samples that were frozen were done so with the intention of mimicking cold stratification to break physiological dormancy which is present in many boreal forest species (Baskin and Baskin 2001). Adhesive trap samples were processed by counting the number of seeds that had been caught in the Bag Balm®, removing the seeds from the trap and placing them in a warm solution of soap and water. This was done to remove Bag Balm® from the individual seeds as the material is hydrophobic and would reduce germination. These seeds were then removed from the solution, dried with paper towel, and transferred to small paper bags. Despite washing of the adhesive trap seeds, the Bag Balm® coating could not be completely removed and prevented the majority of seeds from germinating. As a result, only seed density data was collected from the adhesive traps with little indication of which the species of origin were. The immediately germinated funnel trap samples were kept at 4°C for up to two days in a refrigerator until they were moved to a greenhouse at the Northern Forestry Centre in Edmonton, Alberta. The frozen samples were kept at -15°C in a freezer until May 2015 after which they were germinated in a greenhouse at the University of Alberta in Edmonton.

For the two germination trials (immediately germinated and frozen) each sample was spread across a layer of a peat based growing medium (Sunshine Professional Growing Mix, Sun Gro Horticulture Canada Ltd. in Seba Beach, Alberta, Canada). This growing medium was placed in rectangular potting trays (52cm x 25cm x 6cm). Six samples at a time were placed in a single tray and separated by Coroplast dividers. Once spread across the potting soil surface, the seed trap material was then slightly incorporated into the surface of the potting soil mix. After four weeks the soil surface was re-disturbed through slight raking to encourage additional seed germination. Trays were misted with an automated irrigation system daily to keep soils and their surfaces damp. Trays were rotated weekly to minimize any spatial effect in the greenhouses.

Once specimens could be identified to species they were counted and removed from the trays. Species that could not be identified were left in the trays longer to allow for the production of flowering structures or other identifying features. For the few individuals that could not be identified to species, they were identified to Family or Genus and given a consecutive number behind the taxon (ex. *Salix* sp1). The first germination trial ran from June 2014 to January 2015 and the frozen then germination trial ran from May 2015 to August 2015. A full list of species found in the seed rain analysis is presented in Appendix B.II.

3.2.5 Statistical Analyses

All analyses, unless otherwise specified, were done in R software, version 3.2.2, 64 bit (R Core Team 2015) and an α=0.05 was used to indicate statistical significance.

Total percent cover, percent cover by FFM species, FFM forbs, FFM graminoids, and FFM shrubs in the 2015 belt transects was analyzed to determine if establishment of FFM associated species was occurring in peat outside of FFM islands. This was done using a generalized linear mixed-effects model (GLMM) assuming a negative binomial distribution. All regressions fit normality and heterogeneity requirements, thus data were not transformed. The effect of distance was determined first by running the GLMM using the glmer.nd function with distance as a fixed effect and transect location as a random effect. The significance (p-values) of distance was calculated using Parametric Bootstraps (set at 4999 iterations) with the mixed function from the afex package (version 0.15-2; Signmann et al. 2015). The intercept and slope values for the negative binomial line of fit for each model was calculated using the nls function. This analysis was run in R software, version 3.1.1, 64 bit (R Core Team 2014).

The proportions of total percent cover by FFM associated forbs, graminoids, and shrubs across the distances of the 2015 belt transects were compared to determine what functional groups were contributing to the dispersal out of FFM islands. To do so a linear mixed effect model was executed using the lme function (nlme package vers. 3.1-216; Pinheiro et al. 2016). For the analysis distance was a fixed effect and transect location was a random factor. Tukey's Honest Significant Difference alpha adjustment was used to compare proportions when a significant fixed effect was detected (lsmeans package version 2.20-23; Lenth 2015).

To explore differences in plant communities with distance from FFM islands, cover data from the six quadrats in the 2015 belt transects was subjected to a multivariate cluster analysis. Prior to running the cluster analysis, the data was transformed into a Bray distance matrix using the vegdist function from the vegan package (version 2.3-2; Oksanen et al. 2015). Cluster analysis was then run using the hclust function and cophenetic correlations of the different models were run with the cophenetic function, both from the stats package (version 3.2.2; R Core Team 2015). Based on a cophenetic correlation of 0.909, the Unweighted Pair Group Method with Arithmetic Mean (UPGMA) clustering method was selected. The number of clusters was then determined through interpretation of Mantel statistics and silhouette widths, with a final selection of nine clusters being made. This was selected as a reasonable level of interpretation while maximizing the mantel statistic (0.7) and the average silhouette width (0.27) (Borcard et al. 2011). The silhouette width was calculated using the silhouette function from the cluster package (version 2.0.3; Maechler et al. 2015). To interpret the clusters, species within each cluster that had a greater abundance than the cluster's average species' abundance were determined. While this method is not as robust as determining indicator species values for each cluster, it is still statistically appropriate and provides more species in the output to allow for greater cluster interpretation (Borcard et al. 2011).

To explore what dispersal mechanisms were contributing to the dispersing community out of FFM islands, species present in the FFM portion of the belt transects in 2014 and 2015 were categorized based on their primary dispersal mechanism as described in Flora of Alberta (Moss 1994). Five main dispersal categories were identified for species in the belt transects: 1) gravity dispersed seeds, 2) rhizomes, 3) both rhizomes and seeds, 4) stolons, and 5) wind dispersed seeds. Species were then pooled based on their dispersal category and the maximum and average distance of occurrence into the peat material for the five categories were compared. Average and maximum establishment distances away from the FFM island border of the dispersal categories in 2014 and 2015 were also compared to determine annual dispersal rates. These analyses were done using a linear mixed effect model with year and dispersal category as fixed effects and the transect location as the random effect. In order to meet assumptions of normality and homogeneity of variance, maximum distance values were square root transformed and average distance values were logarithmically transformed. The models were run using the lme function and comparisons of the maximum and average distances were done when a significant fixed effect was found using the lsmeans function and a Tukey adjusted alpha was used for pairwise comparisons of the means (Yandell 1997).

Prior to running analyses on the seed rain data, the emergence data from the immediately germinated and the frozen then germinated funnel trap results across the collection time periods were first merged in order to have seed rain data for the entire growing season. The density of seeds captured with distance from FFM islands was explored to determine if proximity to islands increased seed rain. Germinants from funnel traps were grouped based on the dispersal mechanism their seeds use and their density along the seed rain transects compared to identify which seed dispersal mechanisms were most prominently contributing to seed rain out of FFM islands. The plant functional group (graminoids and forbs) of the funnel trap germinants were also identified and their density along the seed rain transects compared to determine which type of species were dispersing via seeds from the islands. analyses were done with a liner mixed effect model with seed trap type/type of dispersal mechanism/functional group of the seed and distance as the fixed effects and transect location as the random effect. In order to meet assumptions of normality and homogeneity of variance, seed density values for seed trap type and functional group type in the funnel traps were logarithmically transformed and seed density values for the type of seed dispersal mechanism were square root transformed. The models were run using the lme function and comparisons of the maximum and average distances were done when a significant fixed effect was found using the lsmeans function. All seed density pairwise comparisons were done with a Tukey adjusted alpha (Yandell 1997).

Non-metric multidimensional scaling (NMDS) ordination was used to assess the similarity between the species found in the funnel traps with those in the belt transects and islands in 2015. This NMDS was run on an untransformed data matrix with a random starting configuration, a stability criterion of 0.00005, the Bray-Curtis distance measure, and the Wisconsin-style double standardized scaling using the metaMDS function from the vegan package (version 2.3-2; Oksanen et al. 2015). Two dimensions were used for the final graph of the NMDS, including ellipses showing 95% confidence intervals and vectors showing significant association with the ordination (α=0.0001). Ellipses for the NMDS were calculated using the ordiellipse function and vectors were determined using the envfit function, both from the vegan package (version 2.3-2; Oksanen et al. 2015).

3.3 Results

3.3.1 Vegetation Cover

Of the 73 species found in the FFM islands in 2015, 45 were found in the belt transects (Table 3.1). Total vegetation cover (both peat and FFM associated species), cover by FFM associated species, FFM associated forbs, and FFM associated graminoids all significantly decreased with distance from the FFM border in 2015. Shrubs associated with FFM material also tended to decrease, but this trend was not significant (Table 3.2; Figure 3.2). All cover values were highly negatively correlated with distance from the FFM/peat border (Table 3.2).

When explored as a proportion of the total cover, cover of species associated with FFM was higher than cover of species associated with peat, regardless of distance from the FFM border (Figure 3.4A). When broken down into the functional groups, proportion of FFM forbs, FFM graminoids, and FFM shrubs in the 2015 belt transects were significantly affected by distance (Table 3.3). The proportion of FFM forbs was significantly lower in the two quadrats immediately adjacent to the border (FFM, 0m) than in the 20m quadrat. Alternatively, graminoid species accounted for a significantly higher proportion of the total percent cover in the quadrats located immediately adjacent to the border (FFM, 0m) than in the other four quadrats. The quadrat located in the FFM also had a significantly higher proportion of FFM shrubs than the 20m quadrat (Figure 3.4B).

3.3.2 Vegetation Community

Of the nine unique vegetation communities identified from the cluster analysis, only one (cluster 5) was found exclusively in the belt transect quadrats in the FFM, and of the 11 FFM quadrats only one was grouped in this cluster (Figure 3.5). As would be expected in a FFM quadrat, this cluster had above average cover by a number of FFM forb species (*Anemone multifida*, *Aster ciliolatus*); however, *E. angustifolium* was not one of the abundant FFM species. In addition to the FFM forb species, this cluster also had an abundance of grasses (*Agropyron trachycaulum* v. *trachycaulum*, *Oryzopsis pungens*) and ruderal forbs (*Salsola pestifer*, *Lepidium densiflorum*).

The most common UPGMA cluster in the FFM and border position quadrats in the peat was cluster 1; nine of the FFM quadrats and eight of the border position quadrats were grouped in this cluster (Figure 3.5). This cluster was dominated by *E. angustifolium* along with a number of FFM shrubs (*Prunus pensylvanica*, *R. idaeus*), FFM graminoids (*Hierochloe odorata*, *C. canadensis*), and ruderal species (*Crepis tectorum*). The remaining FFM quadrat was grouped in cluster 9, a cluster shared with the border position quadrat of the same transect (Figure 3.5). There were only four abundant species in this cluster although they included a FFM forb (*E. angustifolium*), a FFM shrub (*P. pensylvanica*), a FFM graminoid (*Carex siccata*), and a ruderal species (*C. tectorum*). While not occurring in any FFM quadrats, two clusters (4 and 6) occurred in border position quadrats and were dominated by a number of FFM forbs (*E. angustifolium*, *Potentilla norvegica*) and FFM shrubs (*R. idaeus*, *Arctostaphylos uva-ursi*) (Figure 3.5). These clusters also had abundant ruderal (*Salsoa pestifer*, *C. tectorum*) and graminoid species (*Calamagrostis canadensis*, *Poa palustris*).

The remaining four clusters did not occur in any FFM or border position quadrats and varied in number of occurrences from 20 (cluster 3) to once (cluster 8) (Figure 3.5). Unlike the clusters discussed above, clusters 2, 3, and 8 had abundant species associated with peat material (*Muhlenbergia glomerata*, *Betula pumila*). However, *E. angustifolium* and *P.*

pensylvanica, along with a number of graminoid species (*H. odorata*, *Poa palustris*, *Elymus innovatus*) were also abundant in these clusters. Cluster 7 only had one abundant FFM species (*Carex aenea*) and was dominated by peat (*M. glomerata*) and ruderal species (*S. pestifer*). A full list of the abundant species in each cluster is presented in Table 3.4.

3.3.3 Dispersal Mechanisms

There was a significant difference in both the maximum and the average distance species associated with FFM egressed into the peat material in 2014 and 2015 (Table 3.5). For both measures, distance egressed was greater in 2015 than in 2014 (Figure 3.7). The dispersal category also had a significant effect on both maximum and average egress distance (Table 3.5). Species that have wind dispersed seeds egressed into peat material significantly greater maximum distances than all other categories, while those species that often rely on asexual dispersal through stolons and rhizomes egressed the shortest distances (Figure 3.6). Maximum egress distances by species that can disperse via gravity (large seeds), rhizomes, and a combination of rhizomes and seeds were overall similar (Figure 3.6). Average distance egressed out of islands, while much smaller than the maximum distance, followed a very similar pattern with species with wind dispersed seeds being found the furthest away from the FFM islands in the peat and species utilizing stolons nearest the border (Figure 3.6). However, species that use with both rhizomes and seeds had similar average egress distances to wind dispersed species (Figure 3.6).

3.3.4 Seed Rain

There was a total emergence of 2859 germinants representing 30 species found in the funnel traps and a total of 750 seeds were found in the adhesive traps. Of those 30 species, seven were graminoids, 21 were forbs, and two were shrubs. Sixteen of the 73 species found in the FFM islands in 2015 were captured in the funnel traps in 2014 (Table 3.1). The belt transects and funnel traps shared 15 species (Table 3.1).

Density of seeds captured by the seed traps was significantly affected by the distance from the border (Table 3.6), with seed rain being higher in the FFM and on the border than at 10m and 20m in the peat. Additionally, seed rain density was also higher at the 10m position than at the 20m position (Figure 3.8). There was a significantly higher number of wind dispersed seeds (2451.6 seeds m^{-2}) captured in the funnel traps than of large, gravity dispersed seeds (856.1 seeds m^{-2}). Distance also significantly affected the capture of seeds in the funnel traps; however, there was no significant interaction between type of seed captured and distance from the FFM islands (Table 3.6). Density of captured forb species (2987.2 seeds m^{-2}) was also significantly higher than of graminoid seeds (168.9 seeds m^{-2}; Table 3.6). Forb seeds were captured in significantly higher densities at the FFM and border positions than at 10m and 20m locations although graminoid seed capture density was not significantly different between the four collection distances (Figure 3.9).

3.3.5 Non-Metric Multidimensional Scaling (NMDS)

There was little association between the vegetation communities found in the 2015 belt transects, the 2015 FFM islands, and the 2014 funnel traps. While belt transects and FFM island communities loaded to the top of the vertical axis, the community captured with the funnel traps loaded towards the bottom. However, there was a clear spread along the horizontal axis for the belt transects and the funnel traps that was associated with distance to the FFM islands. Quadrats and traps located nearer the FFM loaded to the left and those located 20m away from the FFM border in the peat material loaded to the right of the horizontal axis. There was more overlap of the collection locations in the funnel traps than in the belt transects. Funnel traps in the FFM, border position, and 10m away from the border in the peat material all grouped together and were driven by the same species, including *E. angustifolium*, *L. densiflorum,* and *Hieracium umbellatum*. Belt transect measurement locations only overlapped at the 10 and 20m locations, both of which were driven by *S. pestifer*. The FFM islands and the belt transect measurements in the peat immediately adjacent to the border had no overlap. However, both the FFM island and quadrats at the border position in the peat were driven by similar species which included a number of shrub (*A. uva-ursi*, *R. idaeus*), forb (*Viola adunca, Polygonum convolvulus*), and graminoid species (*Oryzopsis pungens*, *Calamagrostis canadensis*) (Figure 3.10).

3.4 Discussion

Creating islands within reclaimed landscapes that contain species associated with forests appear to be a useful tool in allowing species to egress into areas where they are currently not present (Robinson and Handel 2000, Winterhalder 2004, Benayas et al. 2008, Corbin et al. 2016). In this study, upland species that were associated with the salvaged forest floor material (FFM) egressed into the peat material and are developing into plant communities similar to the one currently developing on the salvaged FFM. Despite the bulk of the egress out of FFM islands occurring closest to the borders, after four growing seasons the species associated with FFM islands already contributed more to the total vegetation cover than the species associated with peat, this was detectable as far as 20m away from the border. The significant annual increases in distances migrated by FFM species into the peat material further indicates the potential for FFM islands to significantly impact plant communities across reclamation landscapes.

The cluster analysis also reflects the contribution to the vegetation communities in adjacent peat material by FFM species. Nine of the transects had the same community cluster in the FFM island as at the border position in the peat. Within these communities a variety of FFM species of various functional groups were abundant (e.g. *E. angustifolium*, *Hierochloe odorata*, *Arctostaphylos uva-ursi*). This is consistent with other applied nucleation technique studies that have observed herbaceous (Winterhalder 2004), graminoid (Winterhalder 1996), and woody species (Winterhalder 1996, Robinson and Handel 2000, Corbin et al. 2016) dispersing from islands. While forbs and graminoids are important as they are able to quickly establish rooting systems that will stabilize soil (Carroll et al. 2000), shrubs have been found to influence forest floor development, understory composition, and canopy succession (Messier et al. 1998, Lieffers et al. 1999, Timoney 2001). Having a multi-layered community migrating out of the FFM islands is preferable to having a single species dominating the egress as it better reflects a forest community.

Forb species were more dominant along the edge of the egressing FFM community than graminoids, which might be a result of their dispersal mechanisms. Herbaceous species were much more common than graminoids in the seed rain measurements, and wind-dispersed species consistently egressed the furthest distance from the islands. Wind dispersed pioneer species often contribute to the majority of vegetation found around nucleation islands (Winterhalder 1996, Robinson and Handel 2000, Corbin et al. 2016). Vegetative reproduction appears to be the dominant dispersal mechanism for graminoids out of FFM islands. Of the 22 graminoid species observed in the belt transects, only seven were observed in the seed rain and at very low densities. The use of vegetative reproduction by graminoids is supported by their strong decay of germinant distribution with increased distance from the islands as well as a proportionally similar cover in the plots immediately adjacent to the FFM islands. Species which utilize rhizomes and stolons for dispersal consistently had lower dispersal distances than species that use wind dispersed seeds. Herbaceous species are colonizing the peat material by predominantly utilizing wind-dispersed seeds while graminoids are a part of the larger overall community egress out of the islands.

Species which relied on larger seeds did not egress out of FFM islands further than species which utilize vegetative reproduction. Apart from gravity, dispersal by birds and mammals are common mechanisms for which species within the boreal are adapted (Matlack 1994). The isolated location of the ASCS (in the middle of a large mine) is likely a contributing cause of the limited biotic dispersal, as significant increases in plant species which utilize biotic dispersal agents, particularly birds, has consistently been observed in various other nucleation projects (Robinson and Handel 2000, Zahawi et al. 2013, Corbin et al. 2016). The limited use of the islands by biotic dispersal vectors increases the proportion of seed dispersal distance that will need to occur along the ground surface in order to migrate out of the FFM islands.

This increase in seed dispersal along the soil surface is a concern when the surface soil material, as was the case in the peat, is homogenous with little micro topographical variation to provide safe seed beds for establishment. Surface roughness has been identified as an important site characteristic that improves seed retention and germination (Johnson and Fryer 1992, MacKenzie and Naeth 2010, Pinno and Errington 2015). Based on the seed rain analysis there are a number of species that are successfully dispersing seeds out of the FFM islands (e.g. *Solidago* sp., *Lepidium densiflorum*) that are not establishing on the peat. The poor quality of the peat seed bed is also supported by the lack of overlap between the funnel trap and belt transect communities for the same measurement distances in the NMDS and the high seed densities observed in the seed traps. However, the increasing cover of species that successfully establish in the peat material will likely lead to greater seed retention over time around the established vegetation (Johnson and Fryer 1992, MacKenzie and Naeth 2010, Dovčiak et al. 2015). Peat coversoil material has also been found to display hydrophobic properties at the soil surface (Hunter 2011, Leatherdale et al. 2012), which could cause seed desiccation and reduce the germination and establishment success of seeds that were retained on the peat surface.

There were also dispersal limitations in the FFM islands as evident from the low number of shared species between the belt transects and FFM islands. Of the 75 species which were found in the FFM, only 45 occurred in belt transects. Taking into account species that have migrated into the islands and therefore are not FFM species and those found in the funnel traps but not in the belt transects, there were around 20 species that did not disperse out of the FFM islands. These species potentially lacked the needed biotic dispersal vectors (as previously discussed) or they need more time to produce viable dispersal propagules. Alternatively, the large size of the islands (one hectare) may limit the ability of species which use vegetative reproduction or non wind-dispersed seeds to reach the adjacent material.

Despite the challenges with dispersal and seed bed conditions, FFM species from the islands were clearly still able to migrate and establish in the peat material. As a result of its high organic matter content, peat material typically has a high water holding capacity and a high concentration of nitrate (MacKenzie and Naeth 2010, Leatherdale et al. 2012). These material characteristics likely contributed to the dominance of species which use vegetative reproduction, particularly by belowground rhizomes and root sprouts, in the community egressing out of the islands such as *Epilobium angustifolium*, *Rubus idaeus, Hierochloe odorata,* and *Prunus pensylvanica.* These species' reproductive structures were less susceptible than seeds and stolons to desiccation, particularly during the dry 2015 growing season. The dominance of vegetative reproduction in the egressing community is also supported by the low number of species observed in the seed rain. While wind dispersed seeds migrated the greatest distances, species which rely on vegetative reproduction were very prevalent in the egressing vegetation community as they were likely able to access resources in the peat material

(Winterhalder 2004). The bulk of the species migrating from FFM islands using vegetative reproduction explains why the clusters associated with the migrating communities did not extend to the quadrats located five meters in the peat from the border. In four growing seasons, species which migrated using belowground reproductive structures had only egressed an average of half a meter out from the islands. This slow rate of egress as a result of the use of vegetative reproduction has been identified as one of the limitations of nucleation expansion (Robinson and Handel 2000).

The similar seed densities and species found in the traps located in FFM islands and at the border demonstrates that there are currently no physical barriers preventing seed dispersal from the islands. Seed dispersal out of FFM islands is anticipated to decrease as the vegetation matures, as seed movement between forests and grasslands is significantly higher in lower density stands and following leaf drop (Cadenasso and Pickett 2001). As the planted tree seedlings and shrub layers grow taller and the herbaceous layer more pronounced in and around the islands, species which rely on wind dispersal will have less success at getting their seeds out of the islands and into the peat. At that time, the annual rate of increase to the distance egressed out of FFM islands is expected to reduce due to the loss of wind-dispersed seeds. As the structural complexity of the FFM islands increases and movement of wind dispersed seeds decreases, the ability and vigor for many species to reproduce vegetatively within the islands will likely increase as a result of their increased maturity (Zasada et al. 1992). This further reiterates the need to take into consideration island size, particularly with regards to maximizing edge size (Alberta Environment and Water 2011), as vegetative reproduction will become an even greater proponent of the migrating vegetation community as the site develops.

3.5 Conclusions

Within a short timeframe, significant egress of upland species from FFM islands into surrounding reclamation material can occur. Initial colonization is done primarily by wind-dispersed forb species while graminoid species, and to a lesser extent shrub and forb species, which mostly utilize vegetative reproduction are responsible for the bulk of the community egress closer to the FFM island boundary. Although the egress from islands is slow, there were significant annual increases in the distances that FFM associated species were found in the peat, even during dry conditions.

However, the success of FFM islands can be limited due to seed bed conditions both in the surrounding materials and the islands themselves. In our study, seed bed conditions in the peat material had limited establishment of seed dispersed species, potentially as a result of limited seed retention due to soil surface homogeneity and minimal related microsites. Additionally, the size of the islands and the health of the plants within them will also likely contribute to the success of this applied nucleation strategy.

Tables

Table 3.1: Number of common species between the seeds collected in the funnel traps in 2014 and the 2015 vegetation community in the belt transects and FFM islands. Note: 'FT' refers to funnel traps, 'BT' refers to the vegetation in the belt transects, and 'FFM' refers to the vegetation in the FFM islands.

	FT	BT	FFM
Number of common species			
FT	24	15	16
BT	-	51	45
FFM	-	-	73

Table 3.2: Correlation and significance of generalized linear mixed effects model ANOVAs for the effect of distance from the FFM border on total vegetation cover, cover by FFM species, FFM forbs, FFM graminoids, and FFM shrubs (n=11).

Vegetation Cover	Correlation	p-value	Line Equation
Total	-0.714	**<0.001**	$y=10.863e^{-0117x}$
Cover by			
FFM Species	-0.757	**<0.001**	$y=11.209e^{-0.143x}$
FFM Forb Species	-0.637	**<0.001**	$y=4.161e^{-0.084x}$
FFM Graminoid Species	-0.834	**0.001**	$y=5.172e^{-0.420x}$
FFM Shrub Species	-0.834	0.188	$y=2.582e^{-0.117x}$

Table 3.3: Results of linear mixed effects model ANOVAs for the effect of distance from the FFM border on the proportion of total vegetation cover by FFM forbs, FFM graminoids and FFM graminoids (n=11).

Vegetation Cover	p-value
FFM Forb Species	**<0.001**
FFM Graminoid Species	**0.002**
FFM Shrub Species	**<0.001**

Table 3.4: Species which had cover higher than the average per species cover in each cluster. Listed from most to least abundant within that categorization.

Cluster	Most Abundant Species
1$^+$	*Epilobium angustifolium, Hierochloe odorata, Carex siccata, Calamagrostis canadensis, Elymus innovatus, Agropyron trachycaulum* v *trachycaulum, Prunus pensylvanica, Rubus idaeus, Crepis tectorum, Carex aenea, Amelanchier alnifolia, Oryzopsis pungens, Carex tonsa, Rosa acicularis*
2***	*Salsola pestifer, Hierochloe odorata, Amelanchier alnifolia, Salix bebbiana, Populus tremuloides* (Volunteer), *Sonchus* sp., *Muhlenbergia glomerata, Epilobium angustifolium, Agropyron trachycaulum* v *trachycaulum*
3***	*Salsola pestifer, Salix bebbiana, Epilobium angustifolium, Sonchus* sp., *Carex* sp.7, *Prunus pensylvanica, Poa palustris, Aster boreale, Agropyron trachycaulum* v *trachycaulum*, *Amelanchier alnifolia*
4*	*Rubus idaeus, Epilobium angustifolium, Calamagrostis canadensis, Salix bebbiana, Salsola pestifer*
5**	*Arctostaphylos uva-ursi, Agropyron trachycaulum* v *trachycaulum, Crepis tectorum, Anemone multifida, Lepidium densiflorum, Oryzopsis pungens, Aster ciliolatus, Festuca saximontana, Salsola pestifer*
6*	*Prunus pensylvanica, Arctostaphylos uva-ursi, Potentilla norvegica, Amelanchier alnifolia, Carex aenea, Salsola pestifer, Crepis tectorum, Aster laevis, Poa palustris, Agropyron trachycaulum* v *unilateral, Populus tremuloides* (Volunteer)
7***	*Salsola pestifer, Lepidium densiflorum, Carex aenea, Muhlenbergia glomerata*
8***	*Betula pumila, Poa palustris, Elymus innovatus, Prunus pensylvanica, Agropyron trachycaulum* v *trachycaulum*, *Hordeum jubatum, Salsola pestifer, Epilobium angustifolium, Carex aquatalis*
9$^+$	*Prunus pensylvanica, Epilobium angustifolium, Carex siccata, Crepis tectorum*

$^+$ found in FFM and 0m
* found in 0m and beyond
** only found in FFM
*** not found in FFM or 0m

Table 3.5: Results of linear mixed effects model ANOVAs on the maximum and mean distance egressed into the peat by FFM species in 2014 and 2015 (n=11). The effect of year, dispersal mechanisms (and their interaction) on maximum and mean distance was analyzed. Note: 'Y' refers to year and 'DM' refers to dispersal mechanisms (large seeds, rhizomes, rhizomes and seeds, stolons, and wind dispersed seeds).

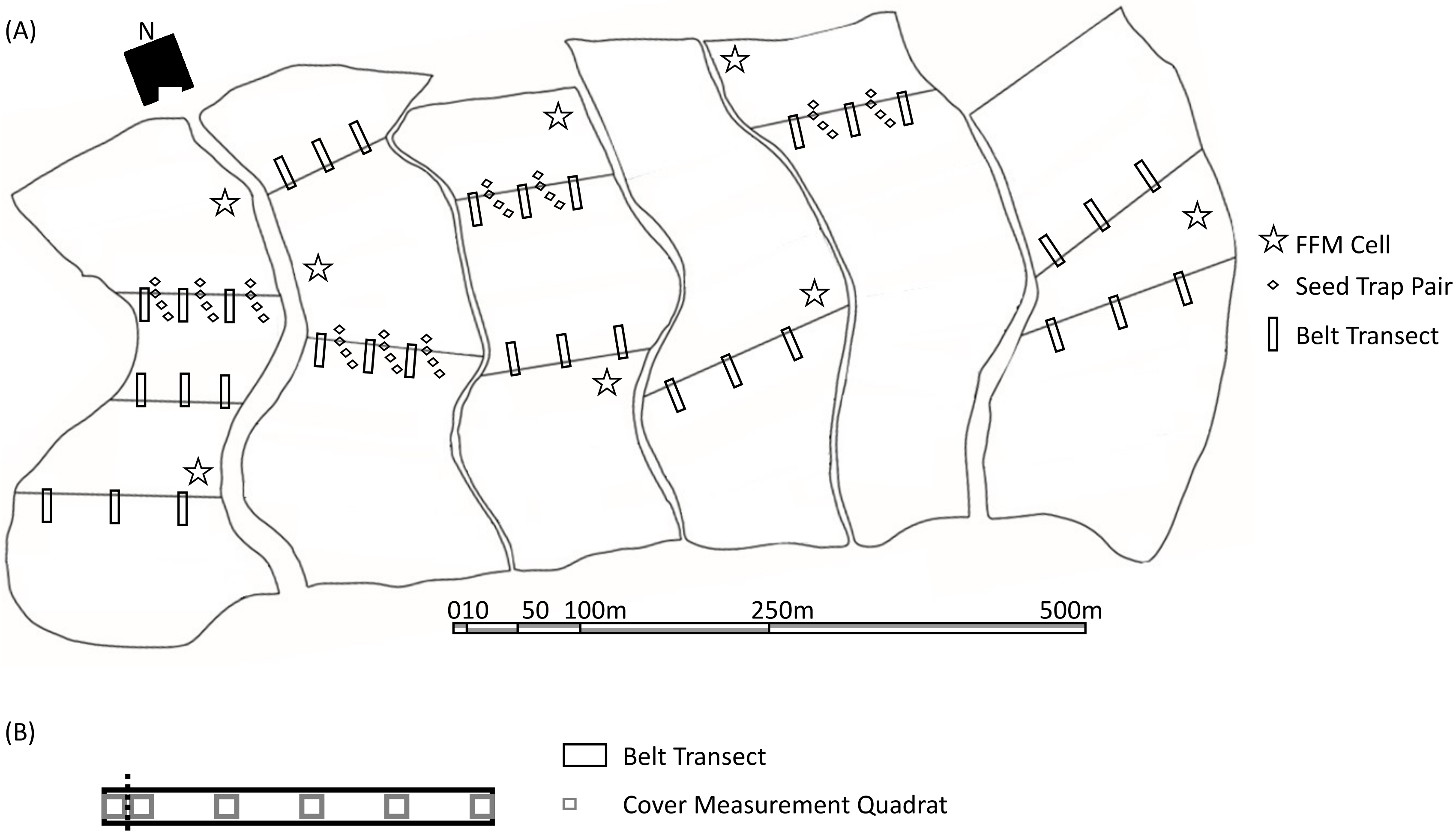
	Max	Mean
Year (Y)	**0.032**	**0.012**
Dispersal Mechanism (DM)	**<0.001**	**<0.001**
Y x DM	0.303	0.249

Table 3.6: Results of linear mixed effects model ANOVAs on the density of seeds between the dispersal mechanism of the seeds capture in the funnel traps and the functional groups of the seeds captured in the funnel traps (n=10). Note: 'TD' refers to seed dispersal mechanism (large seeds and wind dispersed seeds), 'D' refers to distance (FFM, 0m, 10m, 20m), and 'FG' refers to the functional group of the seed (forb or graminoid).

	Seed Density (seeds m^{-2})
Type of Dispersal (TD)	**<0.001**
Distance (D)	**<0.001**
TS * D	0.094
Functional Group (FG)	**<0.001**
Distance (D)	**<0.001**
FG * D	**0.011**

Figures

(A)



(B)

Figure 3.1: Approximate locations of belt transects and seed rain transects across the Aurora Soil Capping Study (ASCS) (A) as well as the layout of each belt transect (B) with regards to location of the vegetation cover measurement quadrats.

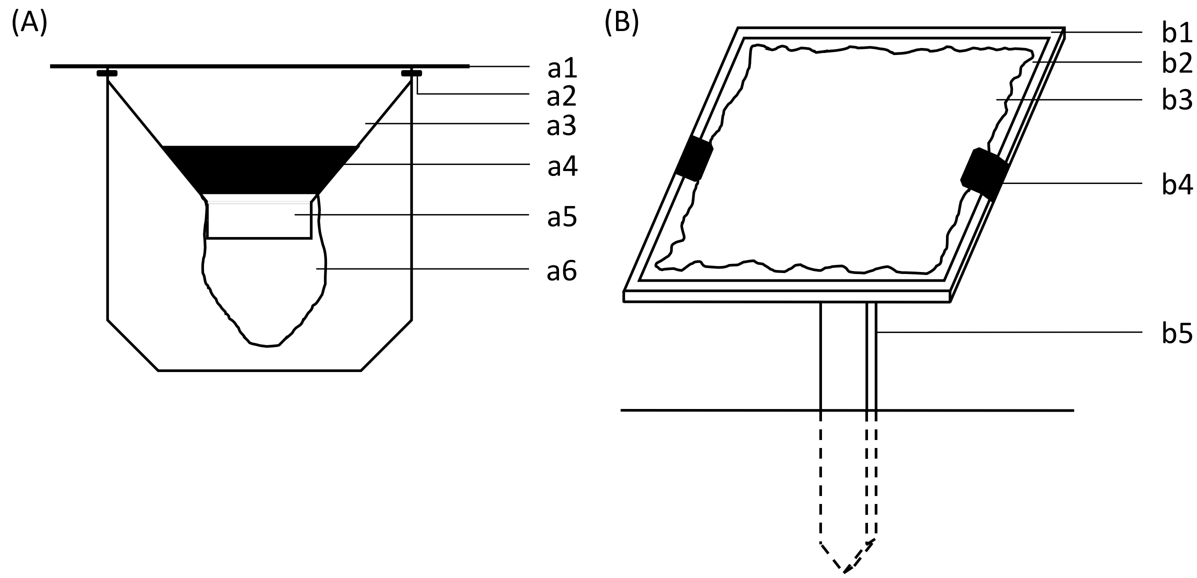


Figure 3.2: Designs for the funnel and adhesive seed traps. The funnel traps were buried to be level with soil surface (a1) and were comprised of a plastic funnel (a3) in an Elite 600® nursery container (a5) with connected by screws (a2). A nylon sock (a6) was held in place at the bottom of the funnel with duct tape (a4). The adhesive trap was composed of a plywood plate (b1) and wooden stake (b5) which formed the frame to which a Coroplast sheet (b2), which had a layer Bag Balm® spread over it (b3), was attached with binder clips (b4). These designs were based on Chabrerie and Alard (2005).

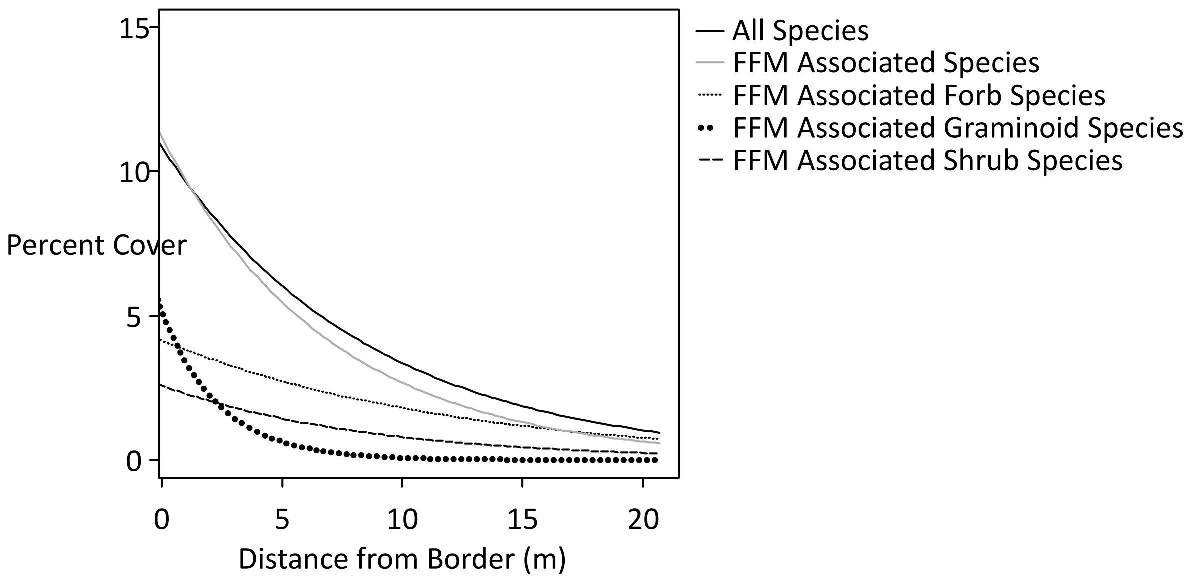


Figure 3.3: Relationship between distance from the FFM border and total vegetation percent cover (solid black line), cover by FFM associated species (solid grey line), FFM associated forb species (black small dashed line), FFM associated graminoid species (black circle line), and FFM associated shrubs (black dashed line) in the belt transects in the 2015 growing season.

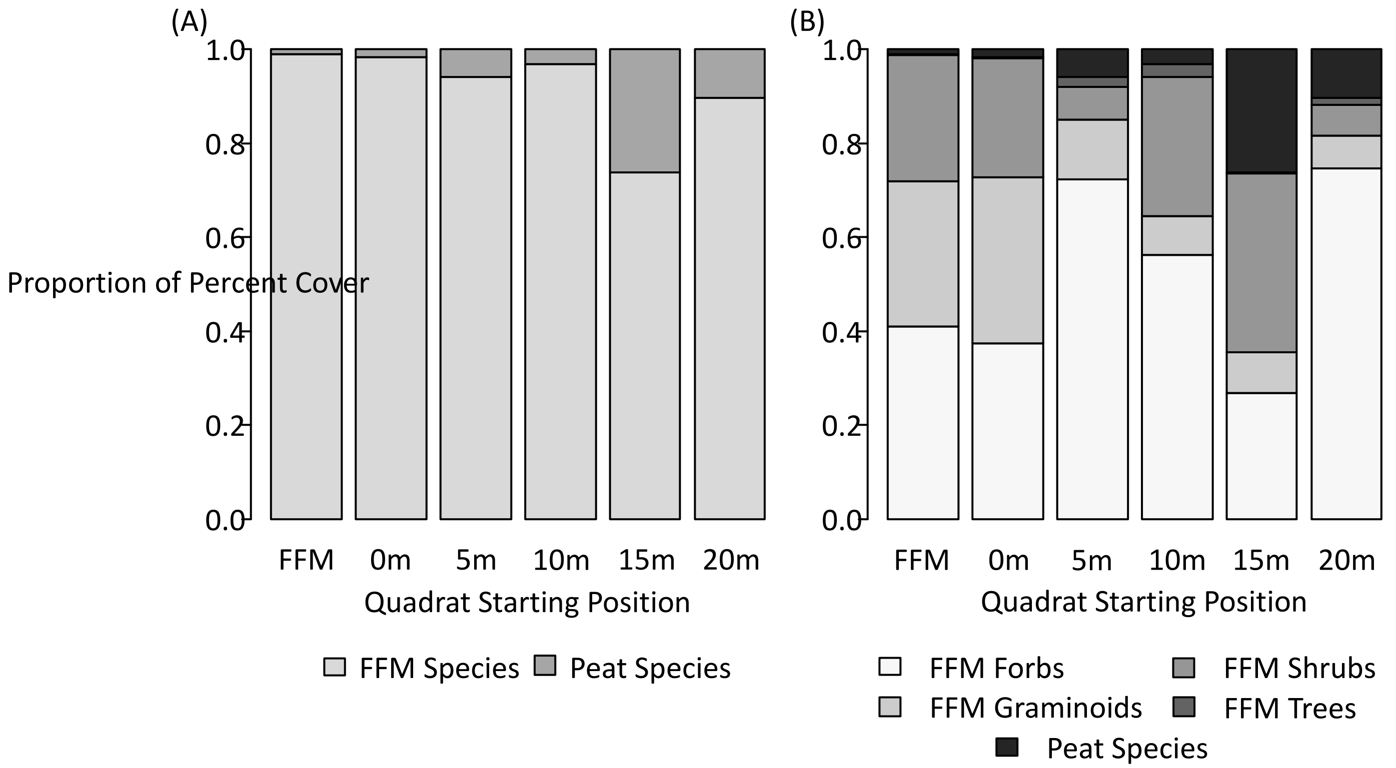


Figure 3.4: Average proportion of total vegetation percent cover in the 2015 growing season between FFM and peat associated species (A), and FFM associated forb, graminoid, shrub, tree species and peat associated species (B) per measurement distance from border. This includes immediately adjacent to the border in the FFM (FFM) and in the Peat (0m) and quadrats at 5, 10, 15 and 20m from the border in the peat.

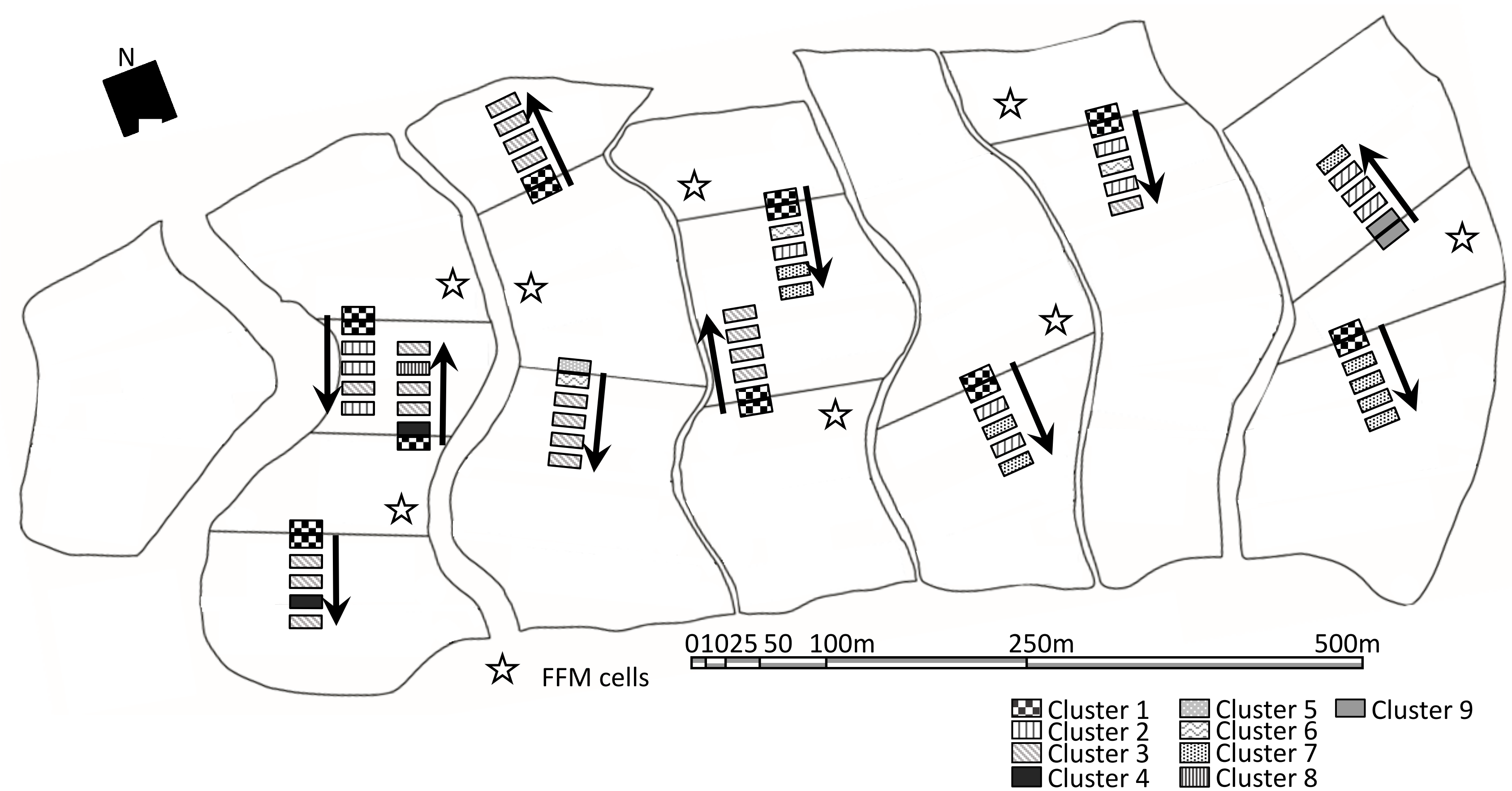


Figure 3.5: Assignment of nine vegetation communities in the six quadrats locations (FFM, 0m, 5m, 15m, 20m) in the belt transects based on the cluster analysis; each cluster is represented by a square pattern/colour. Cells with FFM as the coversoil material are designated with a star and arrows point away from the border into the peat. The quadrat squares are not to scale.

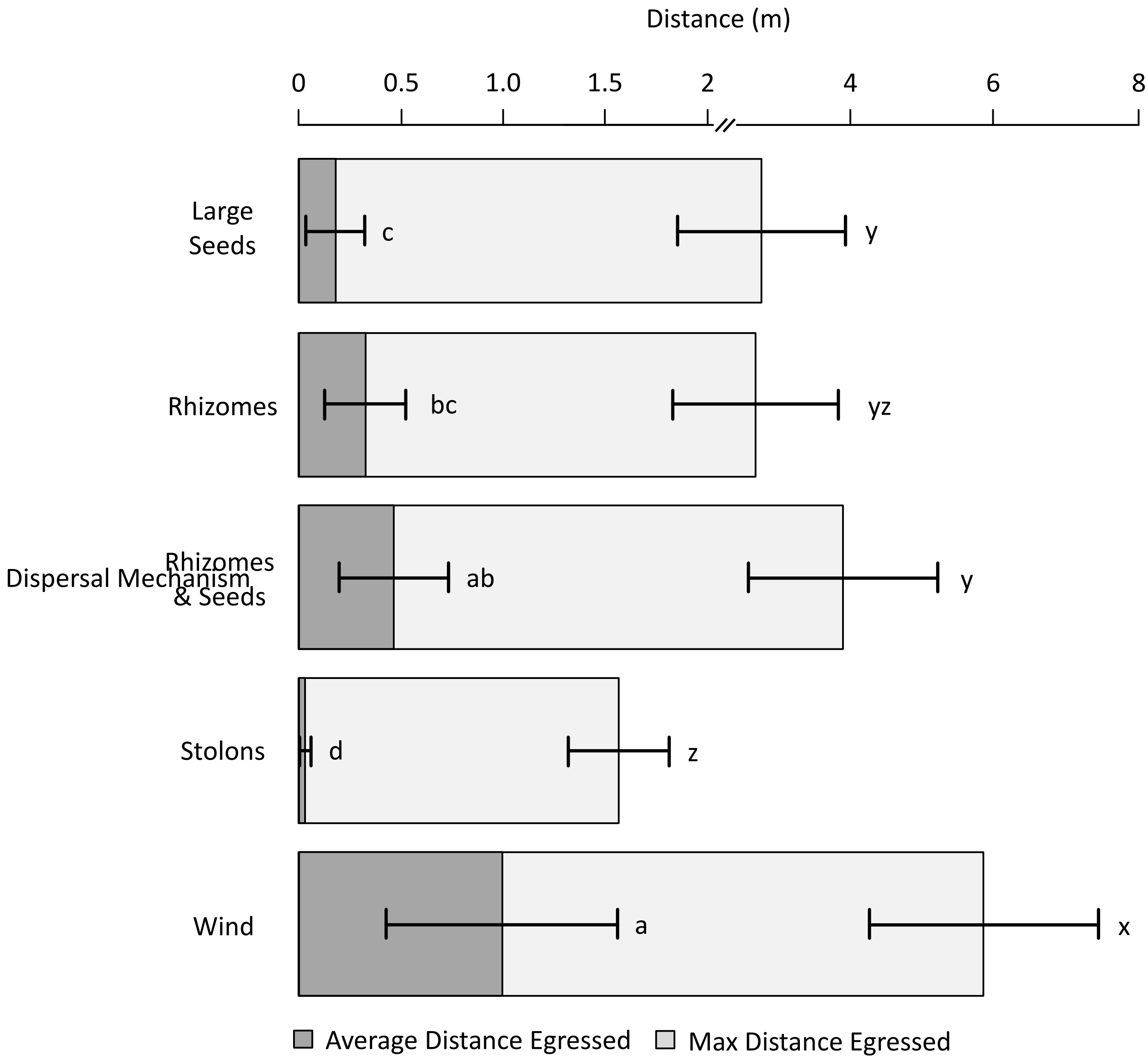


Figure 3.6: Average (dark grey) and maximum (light grey) distance egressed into areas with peat as the coversoil material by FFM species which utilize five different dispersal categories in 2014 and 2015. Bars represent one standard error of the mean and lowercase letters indicate significant differences among the dispersal categories (n=11).

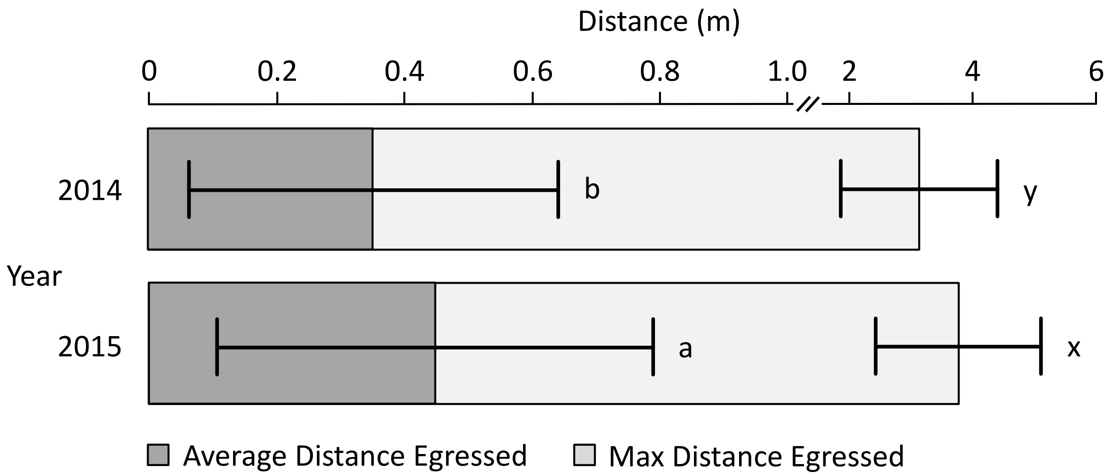


Figure 3.7: Average (dark grey) and maximum (light grey) distance egressed by FFM associated species into areas with peat as the coversoil material in 2014 and 2015. Bars represent one standard error of the mean and lowercase letters indicate significant differences among the years based on the linear mixed effect model ANOVA on transformed data (n=11).

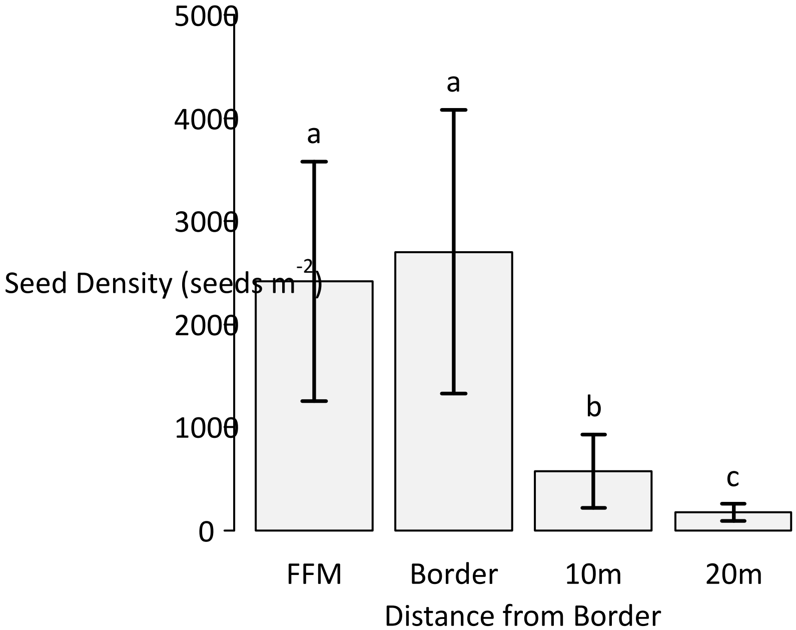


Figure 3.8: Average seed density (seeds m^{-2}) over the entire 2014 growing season (May-October) captured in seed traps (adhesive traps and funnel traps combined) at the four collection locations. Bars represent one standard error of the mean and lowercase letters indicate significant differences based on Tukey adjusted alphas (n=10).

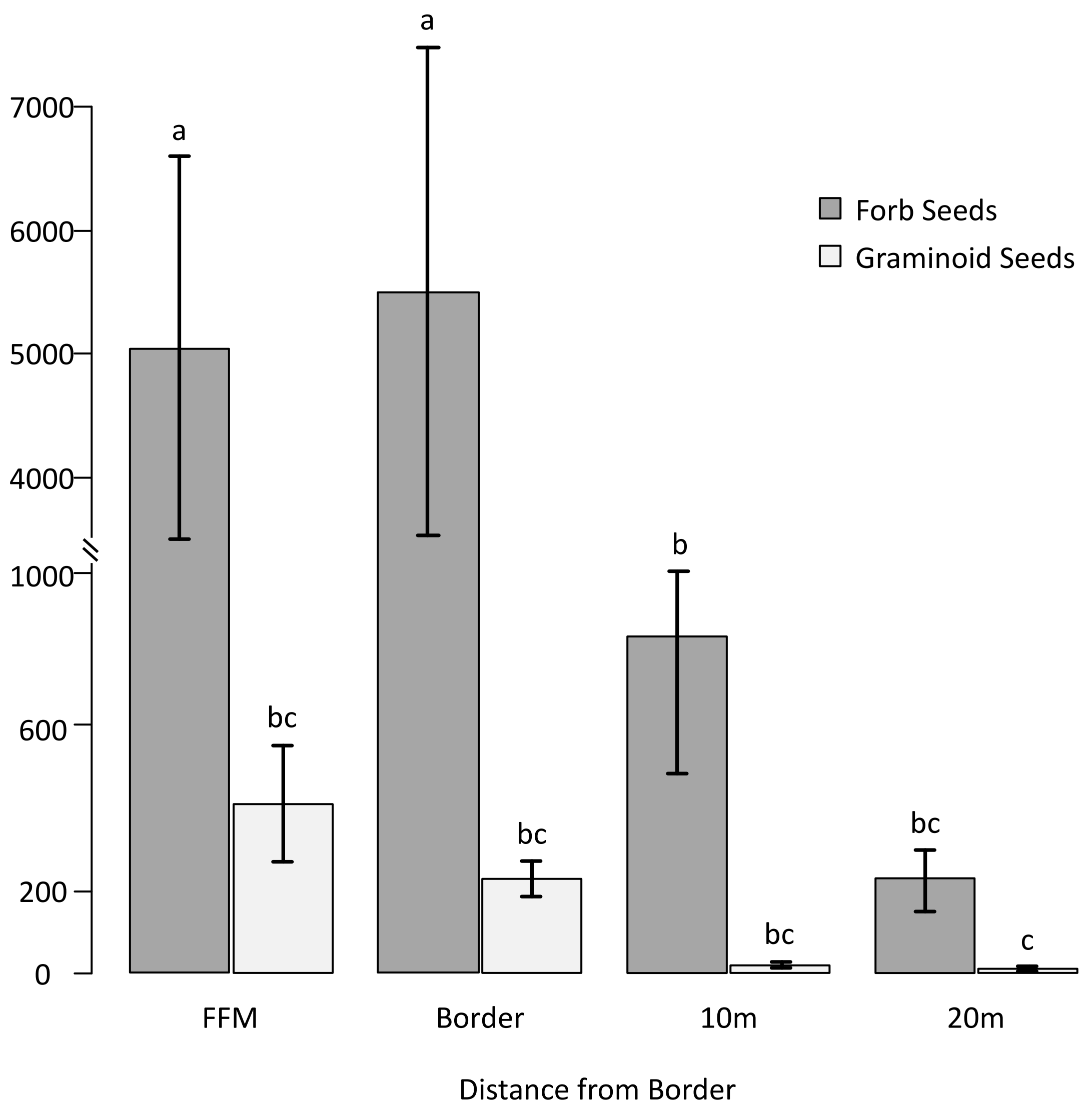


Figure 3.9: Average density (seeds m^{-2}) of seeds from FFM associated forb (dark grey) and graminoid (light grey) species captured in funnel traps over the entire 2014 growing season (May-October) at the four collection locations. Lowercase letters indicate significant differences based pairwise comparisons with a Tukey adjusted alpha (n=10).

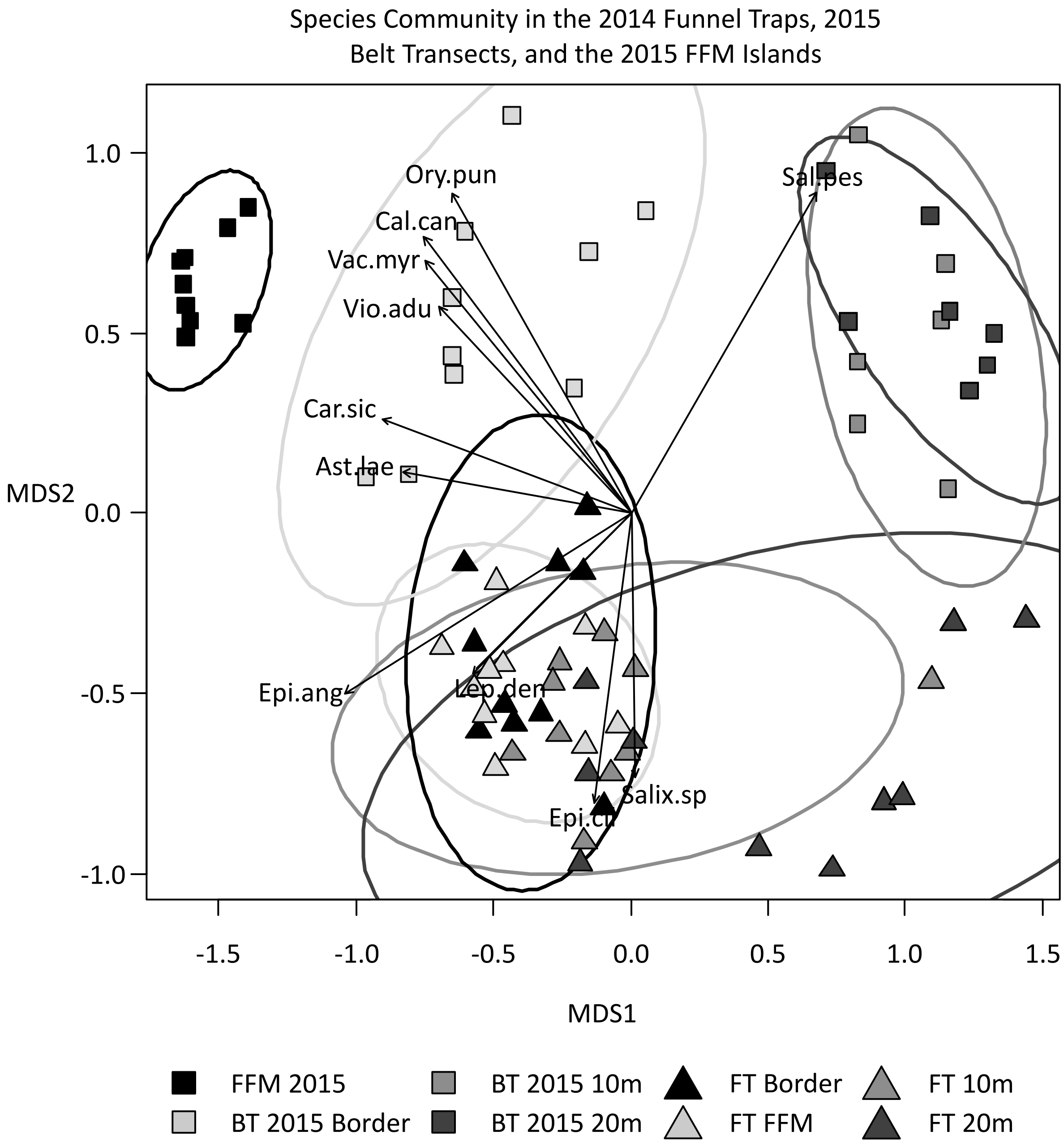


Figure 3.10: NMDS of the species found in the 2014 funnel traps, 2015 belt transects, and 2015 FFM islands (stress=0.148). Ellipses delineate a 95% confidence interval around the centroid of each category and the arrows represent a selection of species that were significantly associated with the NMDS (α=0.0001). A complete list of all the species significantly associated with the NMDS can be found in Appendix B.V.

Chapter 4: Synthesis and Application

4.1 Research Summary

The main objective of this thesis was to explore the effects of different reclamation materials and placement techniques on the development of colonizing vegetation communities in upland reclamation. The first study examined the plant community in response to different coversoil materials, coversoil material placement depths, subsoil material types, total capping depths, planted tree species, and planting densities over three growing seasons. The second study focused on what dispersal mechanisms and species were effective at moving between coversoil materials when a soil translocation applied nucleation technique was used.

The first study examined unplanted vegetation species richness, cover, and community in response to various coversoil materials, subsoil materials, planted tree seedlings, total capping material depth, and underlying subsoil material in the second and fourth growing season at an upland reclamation site. Vegetation in areas where forest floor material (FFM) was used as the coversoil had higher species richness, plant cover, and a community comprised of species found in upland forests than in treatments with peat and subsoils at the surface. Planted tree seedling species had little to no effect in the four growing season. Depth of the coversoil material was only a factor in areas where peat was used, with the deeper treatment having higher vegetation cover, believed to be a result of the increased organic matter and subsequent water holding capacity as compared to the shallow treatment. While total capping depth had little impact on the vegetation, subsoil with higher phosphorous availability resulted in higher cover and richness when placed beneath the coversoil.

In the second study, using FFM as a nucleation strategy within reclaimed landscapes was tested by measuring the egress of species from FFM islands into peat material in the third and fourth growing season. By the fourth growing season, species from the FFM comprised a higher proportion of the vegetation cover than species associated with the receiving material. Forb species comprised a larger proportion of the vegetation cover than graminoids further away from the border; however, graminoid species were a dominant proponent of the bulk of the community egressing out of FFM islands. Wind dispersed species were able to egress out of

FFM islands further than species which utilized gravity dispersed seeds or vegetative reproductive structures. The poor peat seed bed quality limited the capture and germination of many wind dispersed seeds, limiting the success of using FFM as an applied nucleation strategy.

Both of these studies elucidate how reclamation materials and their use impact the colonizing vegetation community in upland forest reclamation. The main driver of the vegetation is the propagule bank contained within the coversoil materials, with the expression of that community being affected by the other reclamation materials used as they influence nutrient, water, and light availability. Nucleation strategies with propagule rich coversoil may be a viable revegetation technique to promote dispersal of native forest species across reclamation landscapes.

4.2 Research Applications

The results of this research demonstrate some of the benefits of strategically utilizing directly placed FFM as it is a valuable source of forest species for upland forest reclamation, particular in the oil sands mining region of Eastern Alberta where lowland communities dominate. In conjunction with appropriate FFM salvage (MacKenzie and Naeth 2010, Macdonald et al. 2015b), placement depth of the coversoil will have a significant impact on the colonizing vegetation community on a reclaimed landscape. Placing less coversoil material will increase the area over which FFM can be applied without negatively impacting community richness and productivity. If this is done in conjunction with the nucleation strategy of placing FFM in islands, the total area which can benefit from the propagule bank within the material will also increase.

Islands need to be large enough to facilitate the development of forest species as they emerge from the FFM propagule bank and placed in a shape that maximizes edge to interior ratio. Making islands too small may increase exposure and decrease the health and vigor of the emerging plants, although making them too large will reduce dispersal by species which utilize vegetative reproduction and non-wind dispersed seeds. Islands also need to be placed strategically; placing them along the edges of reclamation landscapes or near intact forest edges would be inefficient as dispersal of forest species from nearby stands has been observed without the use of FFM islands (Snively 2014).

The effectiveness of the FFM islands in this research study was likely limited by the characteristics of the peat coversoil material surrounding the islands. Challenges such as hydrophobicity, nutrient limitations, and soil surface characteristics could have limited seed capture and establishment (Pinno and Errington 2015) and should be considered when these materials are being used. Application of coarse woody debris on reclamation sites is one way to increase topographical variation which has been found to promote seed germination and establishment (Macdonald et al. 2012, Brown and Naeth 2014, Wilson 2016).

The health and vigor of the plants within the FFM islands is also expected to significantly impact the egress of the community (Dendy et al. 2015). Utilizing soil capping prescriptions with buried nutrients, not only within the FFM islands but in the area surrounding them, will likely increase growth of the FFM vegetation while potentially promoting their expansion, especially with belowground vegetative structures. Egress out of islands will also be influenced by the competition pressure at the leading edge of the expansion (Corbin and Holl 2012). While this was not a concern at the ASCS due to the low vegetation occurrence in the peat, this may not always be the case. If highly competitive species, such as grasses, surround a FFM island the species egress will be severely limited.

It is important to note that the findings and applications of research included in this thesis are limited to the site conditions of this particular study. Generalizations of some results are difficult as site conditions among reclamation sites can vary widely. In addition, the data interpretation is also limited by time as these results are based from measurements that were taken over the first four years of recovery of a reclaimed area. Re-establishment of a forest following a severe disturbance such as surface mining is a complex and lengthy process, and as such more long-term monitoring is needed. However, understanding the early stages of recovery and some of the underlying drivers is a very important aspect of predicting the future trajectory of forest recovery and can be used in predictive modeling. The studies presented in this thesis demonstrate how the propagule banks of coversoils are an important source of vegetation propagules on reclamation sites and how nutrient availability promotes the development of that propagule bank. While the long-term implications of the reclamation materials and placement techniques used in these studies is not known, it is conceivable that without propagule input from external sources, such as FFM islands, the establishment of boreal forest species in the peat material is likely extremely slow. Continued monitoring of the ASCS, as well as other upland boreal forest reclamation sites, will provide better inside and understanding to the long-term effects associated with reclamation material selection and placement techniques.

4.3 Future Research and Study Limitations

Future upland boreal forest reclamation projects would benefit from additional research into the effects that different types of FFM have on the success of the island nucleation strategy. Of the two predominant stand types in the central mixedwood natural subregion, Jack pine stands that have developed on coarse textured Brunisolic soils are the least productive. Trembling aspen-White spruce mixedwood stands that have developed on fine textured Luvisolic soils have greater diversity in their understory communities (Natural Regions Committee 2006), and consequently in their propagule banks. Directly placed FFM salvaged from mixedwood stands produces a more diverse colonizing vegetation community on reclamation sites than when FFM salvaged from pine stands is used (Hoffman unpublished). Consequently, the more diverse vegetation community that emerges from the fine textured FFM may respond differently when placed in a nucleation island than was observed at the ASCS.

Exploring the impacts that the underlying soil material has on the success of FFM islands would also be beneficial. Soil bulk density, soil moisture, nutrient availability, soil pH, soil temperature, and soil texture all have a significant influence on belowground vegetative reproductive structures (Landhäusser and Lieffers 1999). As vegetative reproduction, particularly by rhizomes and root sprouts, has been identified as a significant dispersal mechanism of the egressing community out of FFM islands, understanding the way this is effected by subsoil materials is important. While the FFM at the ASCS was placed atop subsoil material, theoretically these islands could be placed atop LOS or peat material. Understanding how vegetative reproductive structures move through, or around these materials based the soil physical and chemical characteristics will allow for better implementation of the nucleation strategy.

Upland boreal forest reclamation would also benefit from research exploring the difference that adding mineral soil to peat material has on the effectiveness of the material as a reclamation medium. Depending on the quality of the underlying mineral material, soil salvage in lowland areas may only collect the organic soil horizons (Soil Quality Criteria Working Group 2004). However, most research and publications associated with surface mine reclamation in Alberta has utilized peat-mineral mixes (McMillan et al. 2007, Hemstock et al. 2010, Sorenson et al. 2011, Leatherdale et al. 2012, MacKenzie and Quideau 2012, Sloan and Jacobs 2013, Pinno et al. 2014, Pinno and Errington 2015, Schott et al. 2016). Understanding how the two reclamation materials (peat vs peat-mineral mix) differ in terms of their effects on reclamation success, and not only from a colonizing vegetation perspective, would better facilitate those closure plans that involve using pure peat as a coversoil.

In addition to the research questions presented above, continued monitoring of the progress of the ASCS should also be done, particularly as many of the research questions presented in this thesis are still applicable to mature stands. Of particular interest is the effect of the total capping material depth. When the rooting system reaches the LOS material, particularly tree roots, how will that impact the vegetation growth and development? Long-term monitoring of the effects that the different underlying subsoil materials have on the vegetation community development would also be valuable with regards to egress by species which use belowground vegetative reproductive structures from FFM islands.

Monitoring the impacts that the different planting treatments, both species and densities, have on the vegetation community development should also be continued. Although vegetation cover was lower in the high density plots than in the low density plots in FFM, the vegetation community had not yet shifted to include more shade-tolerant forest species. By monitoring the vegetation, in addition to collecting data regarding the canopy cover, a critical canopy level that reduces shade intolerant species could potentially be estimated. The same measurements should also be done with regards to the different tree seedling species. As the tree seedlings grow they are more likely to start having a significant impact on the vegetation, and monitoring of this development could also lead to a better understanding of how much light availability and nutrient input is needed from the canopy species to have a significant impact on the vegetation community.

One of the main limitations of this study was the incomplete study design. The soil capping prescriptions which were designed with the intention of testing the effect of total capping depth were only done with peat material and subsoil (BC/C). Additionally, vegetation and richness were consistently low when subsoil (BC/C) was used as the underlying material, and the treatments which had both high and low density tree plots used subsoil (BC/C). Perhaps if the FFM or subsoil (Bm1) or (C) had been used in these treatments, the more productive vegetation communities would have been effected by the density or capping depth treatments. Not replicating the treatments with all coversoils and subsoils was a missed opportunity; however, there were area and material constraints.

Overall, reclamation studies need to continue to shift away from short-term, single focus studies to more long-term multidisciplinary collaborations like the ASCS. Soil chemical and physical properties, soil biota, vegetation, and wildlife all contribute to ecosystem recovery, and understanding how they influence each other will lead to more effective reclamation techniques. Additionally, better communication of effective reclamation techniques globally should occur. For example, applied nucleation as a restoration technique was introduced in Brazil in the 1990s; however, testing of this technique outside of Brazil has been extremely limited and has primarily focused on only a few nucleation methods. As the bulk of research involving applied nucleation occurs in tropical forests, the associated literature is often initially available in Portuguese and Spanish, limiting the communication and sharing of these studies.

I hope that research presented in this thesis will help influence current forest reclamation practices with regards to the impacts that material selection and placement have on reclamation success, and not only in Alberta.

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Appendices

Appendix A Supplemental Material for Chapter 2

Appendix A.I: Summary of differences in total percent cover and species richness as determined by Tukey adjusted pairwise comparisons based on permANOVAs run for model 2 (n=3). Note: 'TS' represents tree species, 'PD' represents planting density, 'SD' represents coversoil depth, 'CD' represents total capping material depth, and 'ST' represents subsoil material type.

		Total Percent Cover		Total Species Richness	
		FFM	Peat	FFM	Peat
Planting Density	High	2.34 (0.37) **b**	0.19 (0.06) **x**	25.67 (1.45) **A**	10.75 (1.04) **X**
	Low	4.19 (0.27) **a**	0.13 (0.07) **x**	28.17 (1.43) **A**	9.67 (0.71) **X**
Placement Depth	Shallow	7.29 (2.29) **a**	0.21 (0.05) **y**	26.67 (1.20) **A**	8.42 (1.06) **X**
	Deep	6.37 (1.01) **a**	1.41 (0.29) **x**	28.17 (0.76) **A**	9.00 (0.76) **X**
Capping Depth	30 cm	-	0.64 (0.30) **x**	-	17.33 (1.94) **X**
	60 cm	-	1.30 (0.76) **x**	-	16.67 (2.13) **X**
	100 cm	-	0.83 (0.28) **x**	-	11.92 (0.93) **Y**
	150 cm	-	0.19 (0.05) **x**	-	10.75 (1.04) **Y**
Subsoil Material Type	Subsoil (C)	6.37 (1.01) **a**	1.41 (0.29) **x**	28.17 (0.76) **A**	9.00 (0.76) **Y**
	Subsoil (BC/C)	2.34 (0.27) **b**	0.19 (0.05) **y**	25.67 (1.45) **A**	10.75 (1.04) **Y**
	Bm1 + Subsoil(C)	8.24 (1.23) **a**	0.61 (0.18) **y**	36.33 (1.37) **B**	13.83 (1.80) **X**

Appendix A.II: List of all identified species along with their growth form, if they are present in a mature forest understory, and what coversoil material and year they were observed in. Growth forms included graminoid, forb, shrub, tree, and non-vascular; forest species were either characteristic of a mature forest understory or another habit. Species with a '-' before their name could not be identified to the species level but the identified group as a whole from each genus was included in the total species richness. The numbers underneath each of the four coversoil material types indicate if the species was found in 2013 and/or 2015. Note: 'GF' represents growth form, 'F' represents forb, 'G' represents graminoid, 'S' represents shrub, 'T' represents tree, 'NV' represents non-vascular, 'FS' represents forest species, 'Y' represents forest species, 'O' represents other habitats, '13' represents 2013, and '15' represents 2015.

			FFM		Peat		Subsoil(B)		Subsoil(C)	
Species	GF	FS	13	15	13	15	13	15	13	15
Achillea millefolium L.	F	Y	x	x	x	x				
Achillea sibirica Ledeb.	F	Y		x						
Agropyron trachycaulum var glaucum (Link) Gould ex Shinners	G	O	x					x		
Agropyron trachycaulum var trachycaulum (Link) Gould ex Shinners	G	O	x	x	x	x	x	x	x	x
Agropyron trachycaulum var unilateral (Link) Gould ex Shinners	G	O	x	x	x	x	x	x		
Agrostis scabra Wild.	G	O	x	x	x	x			x	x
Alnus crispa (Chaix) DC. (Aiton) Turrill	S	Y	x	x	x	x				
Amelanchier alnifolia (Nutt.) Nutt. Ex M. Roem.	S	Y	x	x	x	x	x			
Andromeda polifolia L.	S	O			x	x				
Anemone canadensis L.	F	Y			x					
Anemone multifida Poir.	F	Y	x	x		x				
Apocynum androsaefolium L.	F	Y	x	x					x	x
Apocynum cannabinum L.	F	Y	x	x	x	x				x
Arabis lyrata L.	F	O			x					
Aralia nudicaulis L.	S	Y	x	x						
Arctostaphylos uva-ursi (L.) Spreng.	S	Y	x	x	x	x		x		
Artemisia biennis Wild.	F	O	x	x		x		x		x
Aster boreale (Torr. & A. Gray) Á. Löve & D. Löve	F	O			x	x				
Aster ciliolatus (Lindl.) Á. Löve & D. Löve	F	Y	x	x	x	x	x	x	x	
Aster laevis (L.) Á. Löve & D. Löve	F	Y	x	x	x	x		x		x
Aster puniceus (L.) Á. Löve & D. Löve	F	Y	x	x		x				
- *Aster* sp. 1	F	Y	x							
Betula papyrifera Marshall	T	Y	x	x						
Betula pumila L.	S	O			x	x				

Bromus inermis Leyss.	G	O	x		x	x	x	x		
Calamagrostis canadensis (Michx.) P. Beauv.	G	Y	x	x	x	x			x	
Calamagrostis inexpansa (Timm) Koeler (A. Gray) C.W. Greene	G	Y	x	x	x	x			x	x
Campanula rotundifolia L.	F	Y	x	x						
Carex aenea Dewey	G	Y	x	x		x				x
Carex aurea Nutt.	G	Y	x		x	x				
Carex rossii Boott	G	O		x	x	x		x		x
Carex siccata	G	Y	x	x	x	x	x	x	x	x
- *Carex* sp. 1	G	O							x	
- *Carex* sp. 2	G	O	x							
- *Carex* sp. 3	G	O	x		x				x	
- *Carex* sp. 4	G	O			x					
- *Carex* sp. 5	G	O							x	
- *Carex* sp. 6	G	O			x		x		x	
- *Carex* sp. 7	G	O	x		x	x				
Carex tonsa (Fernald) E.P. Bicknell	G	Y	x	x	x	x	x		x	x
Carex viridula Michx.	G	O			x	x				
Chenopodium album L.	F	O	x	x	x	x	x		x	
Chenopodium capitatum (L.) Asch.	F	O	x							
Chenopodium rubrum L.	F	O	x			x				
Cirsium arvense (L.) Scop.	F	O				x				
Collomia linearis Nutt.	F	Y	x	x	x		x			
Comandra umbellata (L.) Nutt.	F	O	x	x						
Cornus canadensis L.	S	Y	x	x						
Cornus stolonifera L.	S	Y		x						
Corydalis aurea Wild.	F	Y	x		x	x	x			
Corydalis sempervirens (L.) Pers.	F	Y	x			x				
Crepis tectorum L.	F	O	x	x	x	x	x	x	x	x
Dracocephalum parviflorum Nutt.	F	O	x				x		x	
Elymus canadensis L.	G	O	x	x	x	x	x	x		x
Elymus innovatus (Beal) Pilg.	G	Y	x	x	x	x	x	x	x	x
Epilobium angustifolium (L.) Holub	F	Y	x	x	x	x	x	x	x	x
Epilobium ciliatum Raf.	F	O	x		x	x				
Equisetum arvense L.	NV	Y				x				
Equisetum hyemale L.	NV	Y			x					
Equisetum pratense Ehrh.	NV	Y				x				
Equisetum sylvaticum L.	NV	Y	x							
Erigeron acris L.	F	O						x		
Erigeron canadensis (L.) Cronquist	F	O	x	x	x	x	x	x	x	x
Erysimum cheiranthoides L.	F	O				x				
Festuca rubra L.	G	O		x	x	x				x

Festuca saximontana Rydb.	G	Y	x	x		x		x	x	x
Fragaria virginiana Duchesne	F	Y	x	x		x	x			
Galium boreale L.	F	Y	x	x						
Galium trifidum L.	F	Y	x							
Geranium bicknellii Britton	F	Y	x	x	x	x	x	x	x	x
Hieracium umbellatum L.	F	O	x	x		x				
Hierochloe odorata (L.) P. Beauv.	G	Y	x	x		x				
Hordeum jubatum L.	G	O	x	x	x	x	x	x	x	x
Koeleria macrantha (Ledeb.) Schult.	G	Y		x						
Lathyrus ochroleucus Hook.	F	Y	x			x	x	x	x	
Ledum groenlandicum Oeder	S	Y		x				x		x
Lepidium densiflorum Schrad.	F	O	x	x	x	x	x	x	x	x
Lilium philadelphicum L.	F	Y			x					
Linnaea borealis L.	S	Y		x						
Lobelia kalmii L.	F	O			x					
Maianthemum canadense Desf.	F	Y	x	x						
Matricaria matricariodes DC.	F	O	x							
Medicago sativa L.	F	O					x			
Melilotus alba (L.) Lam.	F	O	x	x		x	x	x		
Melilotus officinalis (L.) Lam.	F	O			x		x	x		
Muhlenbergia glomerata (Wild.) Trin.	G	O	x		x	x	x	x	x	
Oryzopsis pungens (Torr.) Romasch., P.M. Peterson & R.J. Soreng	G	O	x	x	x	x	x	x	x	x
Pinus banksiana Lamb. *(Volunteer)*	T	Y		x		x				
Poa palustris L.	G	O	x	x	x	x				x
Poa pratensis L.	G	O	x	x	x	x				
Polygonum aviculare L.	F	O	x	x	x		x			
Polygonum coccineum L. Michx.	F	O				x				
Polygonum convolvulus L.	F	O	x	x	x	x	x		x	
Polygonum erectum L.	F	O	x		x		x			
Polytrichum juniperinum Hedw.	NV	Y		x						
Populus balsamifera L.	T	Y			x	x				x
Populus tremuloides Michx. (Volunteer)	T	Y		x		x		x		x
Potentilla norvegica L.	F	O	x	x	x	x		x		
Potentilla tridentata (Aiton) Rydb.	F	Y	x	x						
Primula incana M.E. Jones	F	Y			x					
Prunus pensylvanica L. f.	S	Y	x	x	x	x	x		x	x
Ribes oxycanthoides L.	S	Y						x		
Rosa acicularis Lindl.	S	Y	x	x	x	x	x	x	x	x
Rubus idaeus L.	S	Y	x	x	x	x				
Rubus pubescens Raf.	S	Y	x	x						
Salix bebbiana Sarg.	S	O	x	x	x	x				x

Salix candida Flueggé ex. Willd.	S	O			x	x				x
- *Salix* sp. 1	S	O	x		x					
- *Salix* sp. 2	S	O								
- *Salix* sp. 3	S	O	x		x	x				
- *Salix* sp. 4	S	O			x	x				
- *Salix* sp. 5	S	O		x						
- *Salix* sp. 6	S	O		x		x				
- *Salix* sp. 7	S	O			x	x				
- *Salix* sp. 8	S	O	x	x	x	x				x
Salsola pestifer L.	F	O	x		x	x	x	x	x	
Senecio pauperculus (Michx.) Á. Löve & D. Löve	F	O	x		x	x				
Solidago canadensis L.	F	Y	x							
Solidago spathulata Kunth (DC.) Cronquist	F	Y	x	x	x			x		
Sonchus sp. L.	F	O	x	x		x	x	x		
Symphoricarpos albus (L.) S.F. Blake	S	Y	x	x						
Taraxicum officinale F.H. Wigg.	S	O	x	x				x		
Tofieldia glutinosa (Michx.) Baker	F	O			x	x				
Tragopogon dubius Scop.	F	O	x					x		
Trientalis borealis Raf.	F	Y	x	x						
Triglochin maritima L.	G	O			x	x	x			
Triglochin palustris L.	G	O			x	x			x	
Typha latifolia L.	F	O			x					
Urtica dioica L.	F	Y	x		x	x				
Vaccinium myrtilloides Michx.	S	Y	x	x	x	x				
Vaccinium vitis-idaea L.	S	Y	x	x		x				
Vicia americana Muhl. ex Willd.	F	O		x	x		x	x		
Viola adunca Sm.	F	Y	x	x				x		
Total Species Richness = 119										

Appendix A.III: List of all identified species in the four FFM treatments in 2015 along with their growth form, if they are present in a mature forest understory, and what treatment they were observed in. Growth forms included graminoid, forb, shrub, tree, and non-vascular; forest species were either characteristic of a mature forest understory or another habitat. Species with a '-' before their name could not be identified to the species level. Note: 'GF' represents growth form, 'F' represents forb, 'G' represents graminoid, 'S' represents shrub, 'T' represents tree, 'NV' represents non-vascular, 'FS' represents forest species, 'Y' represents forest species, and 'O' represents species from other habitats.

			Treatment			
Species	GF	FS	2	7	8	9
Achillea millefolium L.	F	Y	x			x
Achillea sibirica Ledeb.	F	Y				x
Agrostis scabra Wild.	G	O	x			x
Agropyron trachycaulum var trachycaulum (Link) Gould ex Shinners	G	O	x	x	x	x
Agropyron trachycaulum var unilateral (Link) Gould ex Shinners	G	O	x	x		x
Alnus crispa (Chaix) DC. (Aiton) Turrill	S	Y	x	x		x
Amelanchier alnifolia (Nutt.) Nutt. Ex M. Roem.	S	Y	x	x	x	x
Anemone multifida Poir.	F	Y		x	x	x
Apocynum androsaefolium L.	F	Y			x	
Apocynum cannabinum L.	F	Y	x	x	x	
Aralia nudicaulis L.	S	Y	x	x	x	x
Arctostaphylos uva-ursi (L.) Spreng.	S	Y	x	x	x	x
Artemisia biennis Wild.	F	O	x	x	x	x
Aster ciliolatus (Lindl.) Á. Löve & D. Löve	F	Y	x	x	x	x
Aster laevis (L.) Á. Löve & D. Löve	F	Y	x	x	x	x
Aster puniceus (L.) Á. Löve & D. Löve	F	Y			x	x
Betula papyrifera Marshall	T	Y	x			x
Calamagrostis canadensis (Michx.) P. Beauv.	G	Y	x	x	x	x
Calamagrostis inexpansa (Timm) Koeler (A. Gray) C.W. Greene	G	Y	x	x	x	x
Campanula rotundifolia L.	F	Y			x	x
Carex aenea Dewey	G	Y	x	x		
Carex rossii Boott	G	O	x	x	x	x
Carex siccata	G	Y	x	x	x	x
Carex tonsa (Fernald) E.P. Bicknell	G	Y	x	x	x	x
Chenopodium album L.	F	O				x
Collomia linearis Nutt.	F	Y		x		x
Comandra umbellata (L.) Nutt.	F	O	x	x	x	x
Cornus canadensis L.	S	Y			x	x

Cornus stolonifera L.	S	Y		x		
Crepis tectorum L.	F	O	x	x	x	x
Elymus canadensis L.	G	O	x	x	x	x
Elymus innovatus (Beal) Pilg.	G	Y	x	x	x	x
Epilobium angustifolium (L.) Holub	F	Y	x	x	x	x
Erigeron canadensis (L.) Cronquist	F	O	x	x	x	
Festuca rubra L.	G	O	x			
Festuca saximontana Rydb.	G	Y	x	x	x	x
Fragaria virginiana Duchesne	F	Y	x	x	x	x
Galium boreale L.	F	Y		x	x	x
Geranium bicknellii Britton	F	Y	x	x	x	x
Hierochloe odorata (L.) P. Beauv.	G	Y		x	x	x
Hieracium umbellatum L.	F	O	x	x	x	x
Hordeum jubatum L.	G	O	x	x		x
Koeleria macrantha (Ledeb.) Schult.	G	Y	x	x		
Lathyrus ochroleucus Hook.	F	Y	x		x	x
Ledum groenlandicum Oeder	S	Y				x
Lepidium densiflorum Schrad.	F	O		x	x	x
Linnaea borealis L.	S	Y				x
Maianthemum canadense Desf.	F	Y	x	x		x
Melilotus alba (L.) Lam.	F	O			x	x
Oryzopsis pungens (Torr.) Romasch., P.M. Peterson & R.J. Soreng	G	O	x	x	x	x
Pinus banksiana Lamb. *(Volunteer)*	T	Y	x	x	x	x
Poa palustris L.	G	O	x	x	x	x
Poa pratensis L.	G	O				x
Polygonum aviculare L.	F	O				x
Polygonum convolvulus L.	F	O	x	x	x	x
Polytrichum juniperinum Hedw.	NV	Y	x			
Populus tremuloides Michx. (Volunteer)	T	Y	x	x	x	x
Potentilla norvegica L.	F	O	x	x	x	x
Potentilla tridentata (Aiton) Rydb.	F	Y	x	x	x	x
Prunus pensylvanica L. f.	S	Y	x	x	x	x
Rosa acicularis Lindl.	S	Y	x	x	x	x
Rubus idaeus L.	S	Y	x	x	x	x
Rubus pubescens Raf.	S	Y	x		x	x
Salix bebbiana Sarg.	S	O		x		
- *Salix* sp. 5	S	O				x
- *Salix* sp. 6	S	O	x		x	x
- *Salix* sp. 8	S	O	x	x	x	x
Solidago spathulata Kunth (DC.) Cronquist	F	Y	x	x	x	x
Sonchus sp. L.	F	O	x			x
Symphoricarpos albus (L.) S.F. Blake	S	Y		x	x	x

Taraxicum officinale F.H. Wigg.	S	O		x	x	x
Trientalis borealis Raf.	F	Y	x	x	x	x
Vaccinium myrtilloides Michx.	S	Y	x	x	x	x
Vaccinium vitis-idaea L.	S	Y		x		x
Vicia americana Muhl. ex Willd.	F	O		x	x	x
Viola adunca Sm.	F	Y	x	x	x	x

Appendix A.IV: List of all identified species in the seven peat treatments in 2015 along with their growth form, if they are present in a mature forest understory, and what treatment they were observed in. Growth forms included graminoid, forb, shrub, tree and non-vascular; forest species were either characteristic of a mature forest understory or another habitat. Species with a '-' before their name could not be identified to the species level. Note: 'GF' represents growth form, 'F' represents forb, 'G' represents graminoid, 'S' represents shrub, 'T' represents tree, 'NV' represents non-vascular, 'FS' represents forest species, 'Y' represents forest species, and 'O' represents species from other habitats.

			Treatment						
Species	GF	FS	1	3	4	5	6	10	11
Achillea millefolium L.	F	Y				x			
Agropyron trachycaulum var trachycaulum (Link) Gould ex Shinners	G	O			x	x		x	x
Agropyron trachycaulum var unilateral (Link) Gould ex Shinners	G	O		x	x	x	x	x	
Agrostis scabra Wild.	G	O	x	x	x	x	x	x	
Alnus crispa (Chaix) DC. (Aiton) Turrill	S	Y							x
Amelanchier alnifolia (Nutt.) Nutt. Ex M. Roem.	S	Y				x	x		x
Andromeda polifolia L.	S	O			x	x	x	x	x
Anemone multifida Poir.	F	Y							x
Apocynum cannabinum L.	F	Y		x					
Arctostaphylos uva-ursi (L.) Spreng.	S	Y						x	
Artemisia biennis Wild.	F	O			x	x			
Aster boreale (Torr. & A. Gray) Á. Löve & D. Löve	F	O	x	x	x	x	x	x	x
Aster ciliolatus (Lindl.) Á. Löve & D. Löve	F	Y		x	x	x		x	x
Aster laevis (L.) Á. Löve & D. Löve	F	Y	x	x	x	x	x		
Aster puniceus (L.) Á. Löve & D. Löve	F	Y			x	x			
Betula pumila L.	S	O	x	x	x	x	x	x	x
Bromus inermis Leyss.	G	O				x	x	x	
Calamagrostis canadensis (Michx.) P. Beauv.	G	Y	x		x	x	x	x	
Calamagrostis inexpansa (Timm) Koeler (A. Gray) C.W. Greene	G	Y	x	x	x	x	x		x
Carex aenea Dewey	G	Y				x		x	x
Carex aurea Nutt.	G	Y				x			
Carex rossii Boott	G	O			x	x	x		
Carex siccata	G	Y		x	x	x	x	x	x
- *Carex* sp. 7	G	O		x	x	x			
Carex tonsa (Fernald) E.P. Bicknell	G	Y				x			
Carex viridula Michx.	G	O		x	x	x	x	x	x
Chenopodium album L.	F	O		x			x		

Chenopodium rubrum L.	F	O			x				
Cirsium arvense (L.) Scop.	F	O			x				
Corydalis aurea Wild.	F	Y							x
Corydalis sempervirens (L.) Pers.	F	Y	x	x	x	x	x	x	x
Crepis tectorum L.	F	O		x	x	x		x	x
Elymus canadensis L.	G	O				x	x		
Elymus innovatus (Beal) Pilg.	G	Y	x	x	x	x	x	x	x
Epilobium angustifolium (L.) Holub	F	Y				x			
Epilobium ciliatum Raf.	F	O						x	
Equisetum arvense L.	NV	Y						x	
Equisetum pratense Ehrh	NV	Y	x		x		x		
Erigeron canadensis (L.) Cronquist	F	O							x
Erysimum cheiranthoides L.	F	O	x		x		x	x	x
Festuca rubra L.	G	O		x	x	x		x	x
Festuca saximontana Rydb.	G	Y				x			
Fragaria virginiana Duchesne	F	Y				x			
Geranium bicknellii Britton	F	Y						x	
Hieracium umbellatum L.	F	O			x				
Hierochloe odorata (L.) P. Beauv.	G	Y	x	x	x	x	x	x	x
Hordeum jubatum L.	G	O	x	x	x	x	x	x	x
Lepidium densiflorum Schrad.	F	O				x			
Melilotus alba (L.) Lam	F	O	x	x	x	x	x	x	x
Muhlenbergia glomerata (Wild.) Trin.	G	O	x		x		x		x
Oryzopsis pungens (Torr.) Romasch., P.M. Peterson & R.J. Soreng	G	O		x	x	x			x
Pinus banksiana Lamb. *(Volunteer)*	T	Y	x		x	x			x
Poa palustris L.	G	O			x	x	x		
Poa pratensis L.	G	O			x				
Polygonum coccineum L. Michx.	F	O	x		x	x	x	x	x
Polygonum convolvulus L.	F	O			x	x			x
Populus balsamifera L.	T	Y	x	x	x	x	x	x	x
Populus tremuloides Michx. (Volunteer)	T	Y			x	x	x	x	
Potentilla tridentata (Aiton) Rydb.	F	O	x	x		x	x		
Prunus pensylvanica L. f.	S	Y	x						x
Rosa acicularis Lindl.	S	Y			x	x			
Rubus idaeus L.	S	Y	x	x	x	x	x	x	x
Salix bebbiana Sarg.	S	Y	x	x	x	x	x	x	x
Salix candida Flueggé ex. Willd.	S	O	x	x	x	x	x	x	x
- *Salix* sp. 3	S	O			x	x		x	x
- *Salix* sp. 4	S	O			x				
- *Salix* sp. 6	S	O				x	x	x	x
- *Salix* sp. 7	S	O				x	x		
- *Salix* sp. 8	S	O	x	x	x	x	x	x	x

Salsola pestifer L.	F	O			x	x			x
Senecio pauperculus (Michx.) Á. Löve & D. Löve	F	O	x	x	x	x	x	x	x
Sonchus sp. L.	F	O	x	x	x	x	x	x	x
Tofieldia glutinosa (Michx.) Baker	F	O			x				
Triglochin maritima L.	G	O	x		x		x		x
Triglochin palustris L.	G	O	x		x	x	x		x
Urtica dioica L.	F	Y			x				
Vaccinium myrtilloides Michx.	S	Y		x					
Vaccinium vitis-idaea L.	S	Y						x	

Appendix A.V: Complete list of species with a significant species score (α=0.002) from the NMDS of the vegetation cover communities of the four coversoil material types and years (Figure 2.5). The alpha level was selected to allow for clear delineation on the NMDS of the vectors.

Species	NMDS1	NMDS2	r^2	Pr(>r)
Agropyron trachycaulum var trachycaulum (Link) Gould ex Shinners	-0.44343	0.89631	0.3526	0.001
Arctostaphylos uva-ursi (L.) Spreng.	-0.86867	-0.46539	0.1307	0.001
Carex siccata	-0.90893	-0.41694	0.1700	0.001
Carex tonsa (Fernald) E.P. Bicknell	-0.87502	-0.48409	0.2163	0.001
Crepis tectorum L.	-0.98871	-0.14985	0.2203	0.001
Elymus innovatus (Beal) Pilg.	-0.87919	-0.47646	0.1190	0.001
Epilobium angustifolium (L.) Holub	-0.88691	-0.46195	0.4166	0.001
Erigeron canadensis (L.) Cronquist	-0.95491	-0.29689	0.0986	0.001
Geranium bicknellii Britton	-0.99844	-0.5579	0.1476	0.001
Hordeum jubatum L.	-0.37166	0.92837	0.1386	0.001
Muhlenbergia glomerata (Wild.) Trin.	0.30559	-0.95216	0.1159	0.001
Oryzopsis pungens (Torr.) Romasch., P.M. Peterson & R.J. Soreng	-0.93057	-0.36612	0.1848	0.001
Salsola pestifer L.	0.06113	-0.99813	0.1840	0.001
- *Carex* sp. 7	0.13967	-0.99020	0.1346	0.002
Vaccinium myrtilloides Michx.	-0.95969	-0.28105	0.1075	0.001

Appendix A.VI: Results of Indicator Species Analysis on vegetation cover community composition based on the significant year effect from the perMANOVA for model 2. Given are the specificity values, fidelity values, indicator value (IndVal) statistic, and p-values for significance.

Year	Indicator Species	A[1]	B[2]	IndVal	p-value
2013	*Lepidium densiflorum*	0.94	0.31	0.54	0.003
	Geranium bicknellii	1.00	0.292	0.539	0.001
	Polygonum aviculare	1.00	0.25	0.50	<0.001
	Polygonum convolvulus	0.97	0.19	0.43	0.03
	Erigeron canadense	0.91	0.17	0.39	0.07
	Carex sp.	1.00	0.13	0.35	0.03
2015	*Populus tremuloides* (Volunteer)	1.00	0.27	0.52	<0.001
	Aster laevis	0.70	0.27	0.44	0.057
	Pinus banksiana (Volunteer)	1.00	0.13	0.35	0.023
	Carex sp. 7	1.00	0.13	0.35	0.027
	Festuca saximontana	0.97	0.13	0.35	0.067
	Commandra umbellata	1.00	0.10	0.32	0.058

[1] Specificity or positive predictive value; probability of the species occurring in that group
[2] Fidelity or sensitivity value; probability of finding the species in a site of that group

Appendix A.VII: Summary of results of Indicator Species Analysis on the vegetation cover community composition as they related to the significant year x coversoil material type interaction from the perMANOVA for model 1. Given are the specificity values, fidelity values, indicator value (IndVal) statistic and p-values for indicator species (n=3). Note: '13' represents 2013, '15' represents 2015, 'F' represents FFM, 'P' represents peat, and 'Sb' represents subsoil (Bm2).

Year	Coversoil Material	Indicator Species	A[1]	B[2]	IndVal	p-value
13	F	*Polygonum aviculare*	1.00	1.00	1.00	0.001
		Geranium bicknellii	0.87	1.00	0.93	0.001
		Polygonum convolvulus	0.97	0.67	0.80	0.001
		Erigeron canadense	0.91	0.67	0.78	0.001
		Agrostis scabra	1.00	0.25	0.50	0.014
13	P	*Carex sp.*	0.91	0.42	0.62	0.001
15	F	*Aster laevis*	0.69	1.00	0.83	0.001
		Pinus banksiana (Volunteer)	1.00	0.50	0.71	0.001
		Festuca saximontana	0.97	0.50	0.70	0.001
		Commandra umbellata	1.00	0.42	0.65	0.001
		Carex rossii	1.00	0.33	0.58	0.001
		Poa palustris	1.00	0.33	0.58	0.001
		Rubus idaeus	1.00	0.25	0.58	0.012
15	P	*Salsola pestifer*	0.75	1.00	0.87	0.001
		Carex sp. 7	1.00	0.50	0.71	0.001
13 F, Sb		*Lepidium densiflorum*	0.94	0.63	0.77	0.001
13 F 15 Sb		*Agropyron trachycaulum* v *glaucum*	1.00	0.25	0.50	0.008
15 F, P		*Populus tremuloides* (Volunteer)	0.97	0.46	0.67	0.001
13 F 15 F, P		*Calamagrostis inexpansa*	1.00	0.22	0.47	0.05

[1] Specificity or positive predictive value; probability of the species occurring in that group
[2] Fidelity of sensitivity value; probability of finding the species in a site of that group

Appendix A.VIII: Results of Indicator Species Analysis on the vegetation cover community composition based on the significant coversoil material type effect from the perMANOVA for model 1. For this analysis, the vegetation communities for 2013 and 2015 for each of the coversoil material types were analyzed together. Given are the specificity values, fidelity values, indicator value (IndVal) statistic, and p-values for indicator species (n=3).

Coversoil Material	Indicator Species	A[1]	B[2]	IndVal	p-value
FFM	*Epilobium angustifolium*	1.00	1.00	0.99	0.001
	Oryzopsis pungens	1.00	0.96	0.98	0.001
	Carex tonsa	0.99	0.96	0.97	0.001
	Vaccinium myrtilloides	0.99	0.92	0.95	0.001
	Carex siccata	0.99	0.88	0.93	0.001
	Arctostaphylos uva-ursi	1.00	0.83	0.91	0.001
	Crepis tectorum	0.81	0.92	0.86	0.001
	Elymus innovatus	1.00	0.71	0.84	0.001
	Aster laevis	0.99	0.67	0.81	0.001
	Geranium bicknellii	0.87	0.67	0.76	0.001
	Erigeron canadense	1.00	0.50	0.71	0.001
	Polygonum aviculare	1.00	0.50	0.71	0.001
	Trientalis borealis	1.00	0.50	0.71	0.001
	Amelanchier alnifolia	1.00	0.46	0.67	0.001
	Aster ciliolatus	1.00	0.46	0.67	0.001
	Polygonum convolvulus	0.99	0.46	0.67	0.001
	Prunus pensylvanica	0.80	0.50	0.63	0.002
	Hierochloe odorata	1.00	0.38	0.61	0.001
	Rosa acicularis	0.71	0.42	0.55	0.001
	Festuca saximontana	1.00	0.29	0.54	0.001
	Pinus banksiana (Volunteer)	1.00	0.25	0.50	0.001
	Commandra umbellata	1.00	0.21	0.46	0.004
	Calamagrostis inexpansa	0.95	0.21	0.45	0.015
	Carex rossii	1.00	0.17	0.41	0.013
	Lathyrus ochroleucus	1.00	0.17	0.41	0.014
	Poa palustris	1.00	0.17	0.41	0.017
	Agrostis scabra	1.00	0.13	0.35	0.061
	Artemesia biennis	1.00	0.13	0.35	0.051
	Rubus idaeus	1.00	0.13	0.35	0.059
	Calamagrostis canadensis	0.98	0.13	0.35	0.092
Peat	*Salsola pestifer*	0.78	0.83	0.81	0.001
	Muhlenbergia glomerata	1.00	0.50	0.71	0.001
	Carex sp 7	1.00	0.25	0.50	0.001
	Carex sp 4	0.91	0.51	0.44	0.006
	Sonchus sp.	1.00	0.13	0.35	0.067
Subsoil (Bm2)	*Hordeum jubatum*	0.97	0.63	0.78	0.001

FFM & Peat	*Populus tremuloides* (Volunteer)	0.97	0.23	0.47	0.019
FFM & Subsoil (Bm2)	*Agropyron trachycaulum* v *trachycaulum*	0.99	0.92	0.95	0.001
	Lepidium densiflorum	1.00	0.42	0.65	0.001
	Agropyron trachycaulum v *glaucum*	1.00	0.13	0.35	0.096

[1] Specificity or positive predictive value; probability of the species occurring in that group

[2] Fidelity of sensitivity value; probability of finding the species in a site of that group

Appendix A.IX: Results of Indicator Species Analysis on vegetation cover community composition for model 2, with analysis focused on the four FFM treatments in the 2015 growing season. Given are the specificity values, fidelity values, indicator value (IndVal) statistic, and p-values (n=3).

Treatment	Indicator Species	A[1]	B[2]	IndVal	p-value
2	*Carex aenea*	1.000	0.417	0.645	<0.001
	Moss sp.	0.753	0.417	0.560	0.072
9	*Agropyron trachycaulum* var *trachycaulum*	0.746	0.917	0.827	0.001
	Hierochloe odorata	1.000	0.417	0.645	0.002
	Trientalis borealis	0.867	0.333	0.537	0.076
	Comandra umbellata	0.836	0.333	0.528	0.028
	Rubus ideaus	0.969	0.250	0.492	0.092
7,9	*Elymus innovatus*	0.950	0.583	0.744	0.003
8,9	*Carex tonsa*	0.890	0.667	0.770	0.031
2,7,9	*Vaccinium myrtilloides*	0.955	0.583	0.746	0.060

[1] Specificity or positive predictive value; probability of the species occurring in that group
[2] Fidelity of sensitivity value; probability of finding the species in a site of that group

Appendix A.X: Results of Indicator Species Analysis on vegetation cover community composition for model 2, with analysis focused on the seven peat treatments in the 2015 growing season. Given are the specificity values, fidelity values, indicator value (IndVal) statistic, and p-values (n=3).

Treatment	Indicator Species	A[1]	B[2]	IndVal	p-value
5	*Lepidium densiflorum*	0.556	0.417	0.481	0.024
	Aster ciliolatus	0.750	0.250	0.433	0.060
6	*Agropyron trachycaulum* var *trachycaulum*	0.750	0.250	0.433	0.049
1,6	*Carex* sp 7	0.750	0.333	0.500	0.021
1,3,5,10,11	*Muhlenbergia glomerata*	1.00	0.283	0.532	0.069

[1] Specificity or positive predictive value; probability of the species occurring in that group
[2] Fidelity of sensitivity value; probability of finding the species in a site of that group

Appendix B Supplemental Material for Chapter 3

Appendix B.I: Complete list of vegetation species found in the 2015 belt transects. Included is whether that species was found in the FFM material in 2013 and its growth form functional group. Growth forms included graminoid, forb, shrub, and tree. Note: 'Y' represents species found in the FFM in 2013, and 'N' represents species not found in the FFM in 2013, 'F' represents forb, 'G' represents graminoid, 'S' represents shrub, and 'T' represents tree.

Species	FFM Species	Functional Group
Achillea millefolium L.	Y	F
Agropyron trachycaulum var trachycaulum (Link) Gould ex Shinners	Y	G
Agropyron trachycaulum var unilateral (Link) Gould ex Shinners	Y	G
Agrostis scabra Wild.	Y	G
Alnus crispa (Chaix) DC. (Aiton) Turrill	Y	S
Amelanchier alnifolia (Nutt.) Nutt. Ex M. Roem.	Y	S
Anemone multifida Poir.	Y	F
Apocynum cannabinum L.	Y	F
Arctostaphylos uva-ursi (L.) Spreng.	Y	S
Artemisia biennis Wild.	Y	F
Aster boreale (Torr. & A. Gray) Á. Löve & D. Löve	N	F
Aster ciliolatus (Lindl.) Á. Löve & D. Löve	Y	F
Aster laevis (L.) Á. Löve & D. Löve	Y	F
Betula pumila L.	N	S
Calamagrostis canadensis (Michx.) P. Beauv.	Y	G
Calamagrostis inexpansa (Timm) Koeler (A. Gray) C.W. Greene	Y	G
Carex aenea Dewey	Y	G
Carex aquatalis Wahlenb.	N	G
Carex aurea Nutt.	N	G
Carex rossii Boott	Y	G
Carex siccata	Y	G
Carex tonsa (Fernald) E.P. Bicknell	Y	G
Carex sp. (Tall siccata)	N	G
Chenopodium album L.	Y	F
Corydalis sempervirens (L.) Pers.	Y	F
Crepis tectorum L.	Y	F
Elymus canadensis L.	Y	G
Elymus innovatus (Beal) Pilg.	Y	G
Epilobium angustifolium (L.) Holub	Y	F
Erigeron canadensis (L.) Cronquist	Y	F
Festuca rubra L.	Y	G
Festuca saximontana Rydb.	Y	G
Fragaria virginiana Duchesne	Y	F
Geranium bicknellii Britton	Y	F

Hieracium umbellatum L.	Y	F
Hierochloe odorata (L.) P. Beauv.	Y	G
Hordeum jubatum L.	Y	G
Koeleria macrantha (Ledeb.) Schult.	Y	G
Lathyrus ochroleucus Hook.	Y	F
Lepidium densiflorum Schrad.	Y	F
Melilotus alba (L.) Lam.	Y	F
Muhlenbergia glomerata (Wild.) Trin.	N	G
Oryzopsis pungens (Torr.) Romasch., P.M. Peterson & R.J. Soreng	Y	G
Pinus banksiana Lamb. *(Volunteer)*	Y	T
Poa palustris L.	Y	G
Poa pratensis L.	Y	G
Polygonum convolvulus L.	Y	F
Populus tremuloides Michx. (Volunteer)	Y	T
Potentilla norvegica L.	Y	F
Potentilla tridentata (Aiton) Rydb.	Y	F
Prunus pensylvanica L. f.	Y	S
Rosa acicularis Lindl.	Y	S
Rubus idaeus L.	Y	S
Rubus pubescens Raf.	Y	S
Salix bebbiana Sarg.	Y	S
Salix candida Flueggé ex. Willd.	N	S
Salsola pestifer L.	N	F
Sonchus sp. L.	Y	F
Trientalis borealis Raf.	Y	F
Triglochin maritima L.	N	F
Triglochin palustris L.	N	F
Urtica dioica L.	N	F
Vaccinium myrtilloides Michx.	Y	S
Viola adunca Sm.	Y	F
Total Species Richness: 65		

Appendix B.II: Complete list of vegetation species that germinated form the 2014 funnel seed traps. If the species could not be identified to species level, it was identified to the Family or Genus level and given a consecutive number (ex *Rubus* sp1). Included is whether the species was found in the 2013 FFM islands, its growth form functional group, and if it was found in the immediately germinated samples and/or from the frozen then germinated samples. Note: 'Y' refers to FFM species, 'N' refers to species not found in the 2013 FFM islands, 'G' refers to graminoids, 'F' refers to forbs, and 'S' refers to shrubs.

Species	FFM Species	Functional Group	Immediate Germinate	Frozen & Germinate
Agropyron trachycaulum (Link) Gould ex Shinners	Y	G	√	
Arabis lyrata L.	Y	F	√	
Artemisia biennis Wild.	Y	F		√
Aster ciliolatus (Lindl.) Á. Löve & D. Löve	Y	F		√
Aster laevis (L.) Á. Löve & D. Löve	Y	F	√	√
Carex siccata	Y	G	√	√
Chenopodium album L.	Y	F	√	
Crepis tectorum L.	Y	F	√	√
Epilobium angustifolium (L.) Holub	Y	F		√
Epilobium ciliatum Raf.	N	F	√	√
Erigeron canadensis (L.) Cronquist	Y	F	√	√
Festuca saximontana Rydb.	Y	G	√	
Galeopsis tetrahit L.	N	F	√	
Geranium bicknellii Britton	Y	F	√	
Hieracium umbellatum L.	Y	F		√
Hordeum jubatum L.	Y	G		√
Lepidium densiflorum Schrad.	Y	F	√	√
Matricaria matricarioides DC.	Y	F		√
Potentilla norvegica L.	Y	F	√	√
Rubus sp1	-	S	√	
Salix sp1	-	S	√	√
Salsola pestifer L.	Y	F	√	√
Solidago sp1	Y	F		√
Sonchus sp1	Y	F		√
Taraxicum officinale F. H. Wigg.	Y	F	√	√
Typha latifolia L.	N	F	√	√
Dicotyledoneae sp1	-	F		√
Monocotyledoneae sp1	-	G		√
Monocotyledoneae sp2	-	G		√
Monocotyledoneae sp3	-	G		√
Species Richness = 30				

Appendix B.III: Average proportion of the total percent cover measured in six quadrats along the 2015 belt transects. The averages are distributed between growth form functional groups of the FFM species found in the belt transects. Lowercase letters indicate significant differences within each functional group based on lsmeans (n=11).

Functional Group	Quadrat Location					
	FFM	Border	5m	10m	15m	20m
Forb	0.4 ± 0.0 **b**	0.4 ± 0.1 **b**	0.7 ± 0.1 **ab**	0.7 ± 0.1 **ab**	0.6 ± 0.1 **ab**	0.8 ± 0.1 **a**
Graminoid	0.3 ± 0.0 **x**	0.3 ± 0.1 **x**	0.2 ± 0.1 **y**	0.0 ± 0.0 **y**	0.1 ± 0.0 **y**	0.0 ± 0.0 **y**
Shrub	0.2 ± 0.1 **m**	0.2 ± 0.1 **mn**	0.1 ± 0.0 **mn**	0.2 ± 0.1 **mn**	0.2 ± 0.1 **mn**	0.0 ± 0.0 **n**

Appendix B.IV: Maximum and average distance egressed by FFM associated species into areas with peat as the coversoil material in the belt transects in 2014 and 2015. The average values are also separated by dispersal mechanism. Lowercase letters indicate significant differences between the mechanisms and upper case letters indicate significant differences between the years for the respective response variables based on lsmeans (n=11).

	Distance Egressed (cm)	
	Maximum	Average
Dispersal Mechanism		
Large Seeds	275.9 ± 11.9 **y**	0.4 ± 0.1 **c**
Rhizomes	267.9 ± 116.0 **yz**	32.4 ± 19.9 **bc**
Rhizomes and Seeds	389.6 ± 132.2 **y**	46.3 ± 26.9 **ab**
Stolons	76.4 ± 70.0 **z**	2.7 ± 2.9 **d**
Wind Dispersed Seeds	586.5 ± 160.3 **x**	99.4 ± 56.8 **a**
Year		
2014	313.6 ± 127.5 **Y**	35.1 ± 28.8 **B**
2015	377.5 ± 133.8 **X**	44.7 ± 34.1 **A**

Appendix B.V: Species with a significant species score (α=0.0001) from the NMDS of the species communities of the 2014 funnel traps, 2015 belt transects, and 2015 FFM islands (Figure 3.10). The alpha level was selected to allow for clear delineation on the NMDS of the vectors.

Species	NMDS1	NMDS2	r^2	Pr(>r)
Achillea millefolium	-0.68899	0.72477	0.1867	0.0001
Agropyron trachycaulum	-0.70141	0.71275	0.5491	0.0001
Agrostis scabra	-0.61059	0.79195	0.2558	0.0001
Alnus crispa	-0.75099	0.66031	0.6053	0.0001
Amelanchier alnifolia	-0.48868	0.87247	0.5095	0.0001
Anemone multifida	-0.71501	0.69911	0.3054	0.0001
Arabis lyrata	-0.24609	-0.96925	0.2655	0.0001
Aralia nudicalis	-0.71132	0.70287	0.4373	0.0001
Arctostaphylos uva-ursi	-0.62743	0.77867	0.6450	0.0001
Artemesia biennis	-0.77354	0.63375	0.4296	0.0001
Aster ciliolatus	-0.72121	0.69272	0.4740	0.0001
Aster laevis	-0.99046	0.13783	0.3696	0.0001
Calamagrostis canadensis	-0.70505	0.70916	0.5221	0.0001
Calamagrostis inexpansa	-0.72913	0.68438	0.5530	0.0001
Carex aenea	-0.76096	0.64880	0.2348	0.0001
Carex rossii	-0.71081	0.70338	0.5700	0.0001
Carex siccata	-0.96014	0.27653	0.4651	0.0001
Carex tonsa	-0.66709	0.74498	0.5631	0.0001
Crepis tectorum	-0.90233	0.43105	0.7021	0.0001
Commandra umbellata	-0.72913	0.68438	0.5530	0.0001
Elymus canadensis	-0.72913	0.68438	0.4202	0.0001
Elymus innovatus	-0.70107	0.71309	0.6097	0.0001
Epilobium angustifolium	-0.90451	-0.42644	0.6697	0.0001
Epilobium ciliatum	-0.16180	-0.98682	0.3461	0.0001
Festuca saximontana	-0.72388	0.68993	0.3645	0.0001
Fragaria virginiana	-0.74481	0.66727	0.4311	0.0001
Galium boreale	-0.75766	0.65265	0.2391	0.0001
Geranium bicknellii	-0.69572	0.71831	0.5586	0.0001
Hieracium umbellatum	-0.84275	-0.53830	0.3718	0.0001
Hierochloe odorata	-0.62956	0.77695	0.3565	0.0001
Lathyrus ochroleucus	-0.70167	0.71250	0.4418	0.0001
Lepidium densiflorum	-0.79202	-0.61050	0.2796	0.0001
Maianthemum candense	-0.70426	0.70994	0.2419	0.0001
Oryzopsis pungens	-0.61745	0.78661	0.6609	0.0001
Pinus banksiana (volunteer)	-0.65593	0.75483	0.5189	0.0001
Poa palustris	-0.61609	0.78768	0.2669	0.0001
Poa pratensis	-0.72682	0.68683	0.1872	0.0001
Polygonum convolvulus	-0.76005	0.64987	0.3011	0.0001
Populus tremuloides (volunteer)	-0.33215	0.94323	0.3780	0.0001

Potentilla tridentata	-0.72913	0.68438	0.5530	0.0001
Prunus pensylvanica	-0.60046	0.79965	0.5849	0.0001
Rosa acicularis	-0.72530	0.68843	0.4991	0.0001
Rubus idaeus	-0.65292	0.75743	0.4682	0.0001
Rubus pubescens	-0.70156	0.71261	0.1831	0.0001
Salix sp.	0.02069	-0.99979	0.2801	0.0001
Salsola pestifer	0.60315	0.79762	0.6549	0.0001
Solidago sp.	-0.79537	-0.60612	0.2658	0.0001
Trientalis borealis	-0.74385	0.66834	0.5060	0.0001
Vaccinium myrtilloides	-0.72913	0.68438	0.5530	0.0001
Viola adunca	-0.75229	0.65883	0.4101	0.0001