MINE RESTORATION OF A NATIVE GRASSLAND PLANT COMMUNITY IN THE BRITISH COLUMBIA INTERIOR: THE USE OF BIOCHAR, HYDROSEEDING AND RAKING

By

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ABSTRACT

The extraction of non-renewable resources results in disturbances which alter ecosystems and change landscapes. Semi-arid ecosystems create a unique challenge in the restoration of disturbed ecosystems, as they are water limited. To protect topsoil for future use, mines often strip and stockpile topsoil during the building of infrastructure. Soil amendments and site preparation have been shown to have positive effects in restoration efforts of these disturbed ecosystems. As well, soil preparation, such as tilling, imprinting, use of litter, and hydro-seeding have been used to increase germination and establishment in restoration.

In a greenhouse study, I looked at the effects of biochar as a soil amendment for improving growth of native species indigenous to the semi-arid grasslands of the BC interior. Biochar was mixed at 15% volume by weight to a mixture of 50/50 sand and stockpiled topsoil. Thirty grassland species were studied. Plants were grown in a temperature and humidity controlled greenhouse and harvested after 89 days of growth. Results indicated biochar had no effect on the above or below ground biomass of the native species studied.

My field study looked at the effects of raking and hydro-seeding on the establishment of native species on stockpiled topsoil. The field study was set up and seeded in the fall of 2012. The study consisted of sites raked, hydro-seeded and raked x hydro-seeded. Each factor was either seeded or not seeded with a native seed mixture of 12 forbs and 12 graminoids (200 seeds each) at a seeding density of 1200 seeds/m^2. Seeding natives was found to significantly increase species richness and diversity. For native species overall as well as for the native forb and graminoid functional groups, the use of hydro-seeding showed no significant difference compared to the seeded control. Raking x seed increased establishment rates for native species overall as well as for the two native functional groups.

In conclusion, biochar did not have the intended effect of increased growth on the species studied from the BC interior semi-arid grasslands. However, further research should be conducted using larger pots, increased time, and biochar from different feedstocks. My field study demonstrated seeding of desirable species and site preparation are important aspects of restoration and can influence the direction of succession. However, hydro-seeding was found to have little benefit in the seeding of natives and is not recommended for use in the restoration of semi-arid grasslands. Management should include soil preparation by way of loosening and roughening the soil before seeding. Further techniques in soil preparation and landscaping should be explored to further increase germination and establishment success.

Keywords: Restoration, raking, hydroseeding, biochar, semi-arid grassland, disturbance, diversity and species richness

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CHAPTER 1: INTRODUCTION

Restoration is an important component in the protection and conservation of species and ecosystems. An ever growing human population and their need for resources puts continuing pressure on natural ecosystems. The altered relationship between organisms and their habitats through the spatial and temporal change of a community through a single or multiple event(s) is considered a disturbance (Wali 1999). Activities such as recreation, agriculture, development and industry all contribute to ecosystem disturbances to varying degrees. With the proper forethought, engineering and ecological measures, ecosystems can recover from disturbances in decades to half-centuries (Cullen *et al*., 1998; Jones & Schmitz 2009). Since ecosystem functions are maintained through a high diversity of species, ecosystem functioning is affected by the loss of species (Isbell *et al.* 2011). To preserve ecosystem services, redundancy of organisms with similar functions is important to ensure multiple functions can be sustained in a changing world at any given time (Isbell et al. 2011). Therefore, site specific knowledge is essential to conservation, the restoring of biodiversity and self-sustainability of ecosystem functioning (Yan et al. 2013). The process of restoration involves the rebuilding of physical attributes, reconstruction of hydrological conditions, modifying chemical attributes and manipulating biological activity to attain a self-sustainable ecosystem (Tordoff et al. 2000). Knowledge regarding soil attributes and native flora to be grown are also needed. Thus the process of restoration is a complicated one.

Disturbance

Disturbances can cause a reduction in soil organic matter (OM), and have a negative impact on the microbial community, which in turn can have an effect on soil aggregation, bulk density and pore size and distribution (Wick et al. 2009b). OM can be lost through a reduction in organic inputs, erosion, microbial decomposition or dilution through the mixing of horizons when topsoil is removed and stored for later use (Wick *et al.* 2009a). Fungal communities and plant roots form a network of strands through the soil contributing to the formation of aggregates. Discharge from plant roots, fungal hyphae, bacteria and other micro-organisms within the soil add polysaccharides which also play a role in creating macro and micro-aggregates. This subsurface community can be negatively impacted and/or destroyed through the removal and/or disruption of topsoil (Wick et al. 2009a). Soil aggregates protect organic matter through regulation of decomposition by the microbial community, and this in turn regulates and controls nutrients available for plant uptake. As soil function is closely tied to aggregation (Wick et al. 2009b), the rebuilding of aggregates after a disturbance is an important step in the restoration process.

Where sites are severely disturbed, germination and establishment can be difficult. Processes on these sites may resemble primary succession. If left to natural processes land consisting of exposed rock and poor soil quality can take decades to centuries to return to its historical state (Bradshaw 1997). According to Shu *et al.* (2001) and Roy, Basu & Singh (2002) derelict lands can have scarce organic matter, heavy metal toxicity and extreme soil pH. Thus vegetating derelict wasteland is very slow if left to natural processes as the soil seed bank and soil conditions can be limiting factors (Yan et al. 2013). The end result is dictated by site conditions (soil, water, wind, erosion, nutrients, etc.) and plant communities can differ in composition due to these abiotic factors.

Semi-arid ecosystems are water limited and thus soils tend to be alkaline in nature (Brady and Weil 2012). In these areas, soils are slow to build; and in disturbed ecosystems fungal communities are slow to recover resulting in the slow increase of macro-aggregates within the soil. Therefore, the availability of soil in disturbed semi-arid environments can be a limiting factor in restoration work (Yan et al. 2013). The lack of or high variation in yearly precipitation can also have a negative impact on the germination and recruitment of flora (Bakker et al. 2003). In addition, establishment of plants in semi-arid ecosystems can be limited by extreme seasonal temperatures, the heterogeneity of soil types, sun intensity, high winds, and low fertile soils (Bernstein et al. 2014). As climatic factors are highly variable in semi-arid grasslands, management may be more effective in some years than others (Bakker et al. 2003). As such, direct or indirect facilitation is required to ensure the reverse of desertification or the restoration of semi-arid grasslands through the use of abiotic amelioration, which increases the survival and growth of native species (Pueyo et al. 2009).

Stockpiling Topsoil

Stockpiling topsoil is a way to protect a component of the terrestrial ecosystem when disturbance is imminent from industries such as mining, wellfields, road construction, oil and gas, and development. As biologically active, living soils are fundamental to self-sustaining, functioning terrestrial ecosystems, it is important to protect the soil and its biological, physical and chemical components as much as possible during the storage period. There are challenges to this end, as the mechanical moving of soil and stockpiling for varying lengths of time, sometimes years, makes it difficult to mitigate potential negative effects to the soil and its properties.

Stockpiled topsoil has a tendency to change chemically, biologically and physically over time (Kundu and Ghose 1997). Some of these changes are due to the mechanized handling of the soil and others from the anaerobic conditions that may occur within the heaps (Abdul-Kareem and McRae 1984). Soil properties important to restoration include texture, structure, organic matter and pH. The depth to which changes occur within stockpiled topsoil has been found to be dependent on the type of soil and the depth of the stockpile (Abdul-Kareem and McRae 1984). Chemical changes that can occur within the soil include the forms of nitrogen present, the available nutrients, pH and organic matter levels. Negative biological changes can include reductions in earthworm populations, mycorrhizal fungi and biological biomass within the soil (Abdul-Kareem and McRae 1984). Physical condition of the soil may be altered such that there is a decreased resistance to compaction and aggregate stability, the distribution, size and micro-structure of pores may change, and there may be an increase in bulk density (Abdul-Kareem and McRae 1984, Kundu and Ghose 1997). These physical conditions may come from the process of stockpiling and the use of heavy machinery in the transportation and stockpiling process.

Stockpiling has been shown to affect the seed bank and species richness (Rokich et al. 2000). Depth of topsoil spread, length of stockpiling and mixing of horizons all play a role in the viability of the seed bank found within previously stockpiled topsoil (Dornbush and Wilsey 2010). The time of year the soil is stripped and the seasonal re-introduction of topsoil for restoration may also have an effect on species composition and functional groups (Rokich et al. 2000). Rokich et al. (2000) found a significant decline in the number of seedlings as stockpiles aged from 0 to 3 years old. Young sites or direct return sites had an average seedling count of 131, while 1 year old sites had an average of 71 seedlings and 3 year old sites had 45 seedlings per 5 m^2. This is a decline of up to 66%. This may indicate topsoil stockpiles that are stored for over 10 years may have little left of their seed banks except where soil is exposed to air and water.

Germination and Growth

Soil plays a number of roles for plants, including physical support, water reservoir, protection from toxins, temperature moderation, nutrients and access to below ground air. Soil anchors a plant by its roots allowing it to stand against the elements. Soil that is shallow or poor in structure can result in a weak root support system, thus affecting the plant's ability to physically withstand strong winds or extreme water-saturated soils (Fehmi and Kong 2012). Water found throughout soil pores plays an important role both in providing water to the plant and in helping to move nutrients throughout the soil. The cation and anion exchange capacity of soils can play a role in neutralizing organic and inorganic toxins throughout the soil horizons. Available nutrients are also influenced based on the cation and anion exchange capacity in soils. Nutrients other than oxygen and CO_2 are usually absorbed from the soil solution found within the soil pores (Hopkins and Hunter 2009). As well, the very nature of soil allows it to moderate temperatures thus protecting plant roots and other organisms from the extremes of heat and cold.

The germination of a seed requires water, oxygen and the appropriate temperature (usually between 25° and 45° C). The first step in germination is the uptake of water into the seed or imbibition. The process of imbibition involves the attraction of water to cell walls, proteins and other hydrophilic cellular materials through chemical and electrostatic attractions (Choi *et al.* 2009). As imbibition occurs it activates seed metabolism. This hydration of the seed results in swelling and pressure which causes the seed coat to rupture allowing the embryo to emerge. Germination is complete upon the emergence of the radical. Once the radical makes contact with the soil and water, it can begin the uptake of nutrients which are required for the young seedling to grow. However, poor soil conditions such as degraded sites with little or no organic matter can inhibit germination (Le Stradic *et al.* 2014). Le Stradic *et al.* (2014)

found that latosol substrate (a tropical soil high in iron and aluminium oxides) had fewer seedlings than sandy or stony substrates no matter the method of seed sowing (use of hay or geotextile).

Some species have additional requirements besides oxygen, water and temperature in order for them to germinate. These seeds lay dormant until the appropriate environmental conditions trigger the seed out of its dormant state (Hopkins and Hunter 2009, Penfield and King 2009). Others have a seed coat that is impermeable to water or oxygen, and some have to go through further physiological changes (ripening) after being released from the parent plant. For some, these physiological changes occur when the seed is exposed to low temperatures, such as a winter season. Dormancy is then broken when the temperatures warm in the spring. Other seeds require scarification. This can be accomplished through abrasion by the surrounding soil medium, microbial action, or passage through an animal's gut. Removal of the seed coat can allow water and/or oxygen into the seed thus allowing for metabolic processes to begin and the seed to germinate. Light and hormones can also have an effect on dormancy (Hopkins and Hunter 2009, Penfield and King 2009).

Site Preparation

Soil Amendments

In an attempt to restore disturbed land, different techniques involving substrate amelioration, soil amendments, soil preparation, and selection of plant species have been used (Wilson and Gerry 1995, Cullen et al. 1998, Tordoff et al. 2000, Holmes 2001, Cosgriff et al. 2004, Loydi et al. 2013). As disturbance can reduce OM and decrease aggregates within soil, amelioration and amendments may be needed to restore the soil thus allowing for successful revegetation. The process of soil building through the addition of organic matter, which usually comes in the form of plant litter and roots, takes time (Bradshaw 1997). As the desire is usually to restore an area quickly, expediting the process of soil building is key. The addition of soil amendments such as manures, biosolids, plant litter, and biochar have been used with some success (Tisdale and Nelson 1975, Tandy et al. 2011, Ohsowski et al. 2012, Mollard et al. 2014). These same studies have also shown that the addition of organic carbon (OC) can result in increased plant biomass by as much as 72%. It's possible that weeds may also be controlled by the addition of carbon. Blumenthal (2008) showed that an increase in OC can decrease weed success by 52%. It's possible this weed suppression is the result of soil microbes immobilizing plant available nitrogen (N) in the presence of a large pool of OC (Blumenthal, *et al.* 2013).

Plant litter as a form of C can affect seed germination, and this success can also be dependent upon seed size. Smaller seeded species can be negatively affected by the amount of litter used (Facelli 1991). Through a meta-analysis Loydi *et al.* (2013) revealed that in grasslands the addition of litter resulted in changes in moisture level and an increase in seedling emergence. Tandy *et al.* (2011) showed that differing forms of compost used in grassland restoration, such as greenwaste and biosolids, resulted in increased plant cover from 36% to 56%. Farrell *et al.* (2011) had similar results in a study that looked at greenwaste and sewage sludge. In recent years, C in the form of biochar has gained interest. Biochar by definition is the bi-product of organic matter heated in a low oxygen environment at low temperatures (<700°C) for the sole purpose of amending soil (Lehmann and Joseph 2010). Unlike burning, which creates ash and therefore contains little or no organic carbon, charring or pyrolysis results in a product which contains varying ratios of OC and C, dependent on the feedstock used and method of pyrolysis.

Biochar is not a new product. Evidence can be easily found as to its historical use in Europe and North America in the early 1900s as an amendment to potting soil, and the earliest recorded date of 1697 where it was used in agriculture to amend soils. Both of these uses claimed biochar added to soils resulted in higher production (Uzoma et al. 2011, Olmo et al. 2014). In the last 25-30 years research and development of biochar for environmental management has increased. The very makeup of biochar makes it an interesting candidate for amending soils in the field of restoration. Indications are that biochar is a stable form of carbon within the soil environment and can increase nutrient availability through increased cation exchange capacity (CEC) beyond the effects of a fertilizer (Lehmann et al. 2003, Liang et al. 2006a, Novak et al. 2009b). There is also support for the theory that biochar is more effective than other forms of organic matter in the soil due to its chemical and physical properties (Novak et al. 2009b, Prendergast-Miller et al. 2011). Biochar has a high charge density (charge distribution (-/+) to particle volume), which results in overall greater nutrient retention. Biochar's particulate make-up and its chemical structure also result in a resistance to microbial decay (Cheng et al. 2008).

Biochar seems to have a number of beneficial uses such as soil improvement (productivity and/or pollution reduction), waste management, climate change mitigation, and energy production. In turn these uses in combination can have social and/or financial benefits (Lehmann and Joseph 2010). In terms of soil health and food security biochar may be an important addition to soil management practices as it has been shown to have the ability to increase the efficiency of added fertilizers while reducing the impact on soil and water resources (Lehmann et al. 2003, Bouwer et al. 2015). In developing countries where fertilizers may be cost prohibitive, biochar is a soil amendment that can be produced from existing resources; therefore, making it an accessible soil amendment. The use of local organic matter can help to manage waste thus benefit the local communities as well as local ecosystems. Biochar, being a stable form of C, may also contribute to climate change mitigation by increasing soil carbon stores.

Soil preparation and seeding methods

Soil preparation and seeding are techniques used to revegetate disturbed areas. Methods for soil preparation have included natural (spontaneous) restoration (Kirmer and Mahn 2001) or manipulative restoration techniques such as the replacing of topsoil to different depths (Dornbush and Wilsey 2010), addition of fresh plant clippings (Kirmer and Mahn 2001, Baasch et al. 2012), burning, tillage, and use of herbicides (Schreiber 1992; Wilson & Gerry 1995; Mangold *et al.*, 2013). Seeding methods have included hydro-seeding (Soliveres *et al.*, 2012), drill seeding, imprinting, hay transfer and broadcast seeding (Yurkonis et al. 2008, Bernstein et al. 2014). Left to natural processes restoration of disturbed areas can be slow due to poor seed supply and dispersal (Kirmer and Mahn 2001) and poor soil conditions (Bradshaw 1997). Manipulative restoration experiments have had varied success. Burning and herbicide treatments resulted in the removal or decrease of unwanted species before desirable species were seeded. However, the effect of burning was found to be dependent on species (Moog et al. 2002). Herbicide treatments, while increasing the success of native species and removing unwanted target species (Wilson and Gerry 1995, Mangold et al.

2013), may be undesirable because of the use of chemicals or compounds that may be harmful to organisms other than the target species. Tilling can have a number of benefits: it can increase soil porosity allowing for better root penetration and access to water and nutrients; increase water infiltration rates ensuring water moves down into the soil rather than remaining near the surface; and increase surface heterogeneity (Wilson and Gerry 1995, Montalvo et al. 2002, FLH Western Federal Lands Highway Division 2007). Tilling has been used to remove unwanted species while also playing a role in reducing soil compaction. Bottoms & Whitson (1998) found that tilling reduced the number of Russian Knapweed (*Centaurea repens*) and Cosgriff *et al.* (2004) found tilling reduced the number of false hellebore, but this type of disturbance may also open an area up to other invasive species. In a study by Liu *et al.* (2008) harrowing combined with broadcast seeding resulted in greater emergence and establishment over broadcast seeding alone, and (Pueyo et al. 2009) found greater growth when a plough treatment was used to prepare the soil.

Different seedbed preparations have given different results in reclamation and restoration projects. Broadcast seeding, while sufficient in adding desirable species to the seed bank, may not give the needed preparation to the seedbed for optimal germination and establishment (Montalvo et al. 2002). However it has been shown to facilitate native grass establishment (Yurkonis et al. 2008). Tilling and ripping, through the use of tines or discs, penetrate and loosen the soil leaving behind furrows of set depths before planting occurs, but also result in disturbance to the soil. Imprinting, on the other hand, is done after seeding and creates impressions in the soil while also pushing seeds into the top layer creating better seed-soil contact. Tilling, ripping, and imprinting can result in an increase in germination and establishment, but may depend on climate, soil, and species seeded (Wilson and Gerry 1995, Dornbush and Wilsey 2010). Drill seeding is the creation of holes within the soil at a set depth and distance apart. Drill seeding has had positive results, but depends upon the depth of the drill hole and species used as well as soil properties (Bernstein et al. 2014). Drill seeding was also found to increase the number of exotic species in some cases (Yurkonis et al. 2008). Hydro-slurry is a mix of mulch fibre, tackifying agent, water, fertilizer (optional) and the desired seed mixture. The use of hydro-slurry in reclamation projects is not new (Sheldon and Bradshaw 1977, Merlin et al. 1999, Montalvo et al. 2002, De Oña et al. 2011); however, the success of hydro-slurry is somewhat controversial. Some studies have had positive results while other studies have indicated hydro-slurry can suppress germination and establishment of desirable species (Muzzi et al. 1997, Martínez-Ruiz et al. 2007, Dunifon et al. 2011). As ecosystems have unique qualities, site specific research in the area of site preparation and seeding method is important in attaining the desirable plant community.

Restoration

In an effort to reduce wind and water erosion, control the spread of exotic species, and protect or re-establish ecosystem services, reconstructing ecosystems to a self-sustainable state is necessary. As the need for resources continues to increase due to a growing global population, environmental protection through ecosystem restoration projects has also become increasingly important. Re-establishing vegetation is both a cost effective and an environmentally sustainable solution to rehabilitating disturbed and damaged ecosystems (Yan et al. 2013).

In Canada, industries such as mining, oil and gas, pipelines, and road infrastructure are required to reclaim or restore the ecosystems they disturb. To this end, industries can choose to reclaim or restore the disturbed area. Reclamation is the use of species that may include agronomics to return an area back to its pre-disturbance productivity level. Restoration, on the other hand, uses native species in the process of returning an ecosystem that has been damaged back to its natural self-sustainable state (Alday *et al.* 2011a). For mining, this means restoring the pre-mining landscape and vegetation to a state where it contains sufficient biotic and abiotic resources to continue development without further assistance. This process may be constrained by economics, availability of seed, germination success, and establishment success. As well, native seed can be difficult or impossible to source at the scale needed for bigger restoration projects especially in terms of forb species (Rowe 2010). Martin & Wilsey (2006) demonstrate that the addition of seed is imperative to ensure higher diversity values and to reintroduce rare plants back into disturbed ecosystems. Left to natural processes, restoration can take decades, even centuries, to return to its natural self-sustainable state, if it at all (Baasch et al. 2012).

Restoration can accelerate the recovery of native vegetation to a site by decades. This is especially the case in harsher environments like that of semi-arid grasslands. Site specific factors such as historical land use, evolutionary time scale of community assemblage, the make-up of the surrounding landscape including availability of native propagules, use of the area by herbivores, predators and pathogens, and the abiotic conditions of the site are all important factors influencing the successful restoration of disturbed areas (Grman *et al.*, 2013). According to Burke (2003) there are two main aspects to restoration: 1) suitable substrate and landforms which mimic the natural landscape; and 2) the facilitation of natural processes. Site preparation should be completed with prevailing winds in mind as landforms and smaller scale heterogeneity play a role in slowing wind and water erosion as well as creating catchments for soil, water, seed and litter (Burke 2003). Facilitation may be accomplished through the use of pioneer plants and may contribute to ameliorating the soil through the addition of organic matter, alteration of soil chemistry, and attracting insects and soil organisms. Mycorrhizal fungi also help to facilitate restoration processes when seeding or re-vegetating indigenous species (Burke 2003). Hence pioneer plants may also play a role in the reintroduction of native mycorrhizal species to the area.

Restoration as an active process requires management in order to influence the outcome of the resultant plant community (Grman et al. 2013, Yan et al. 2013). The sowing of native species has been shown to increase diversity and influence the community structure (Baasch et al. 2012). Grman *et al.* (2013) found that non-seeded species had lower diversity levels when desirable forbs were seeded at higher densities. Therefore, seed mix is important in managing the diversity of a disturbed ecosystem. As well, seeding native species can result in an ecosystem's increased ability to capture light, have higher primary production resulting in greater root and litter biomass and therefore greater carbon sequestration (Foster et al. 2007). It is important too that restoration and the seeding of native species is a priority in order to establish natives as early as possible (Martin and Wilsey 2012) in an attempt to mitigate erosion and reduce access to open land by exotics.

Mining

The mining and mineral industry represents billions of dollars which contribute to Canada's Gross Domestic Product (GDP) as well as in tax dollars and royalties to both the federal and provincial governments. Thus mining is an important economic driver in Canada and employs approximately 400,000 people across the country (“The Mining Association of Canada” 2014). In British Columbia, the gross mining revenue amounted to $9.9 billion in 2011. Tax and royalties to the BC government amounted to $805 million and spin offs from the mining industry provided a further $3 billion in direct industry expenditures (“The Mining Association of BC” 2013). The direct and indirect economic impact, as stated by PricewaterhouseCoopers Canada in their Economic Impact Analysis in 2011, was $8.9 billion in BC for 2010.

Mining, however, by its very nature is destructive and creates highly disturbed areas through the building of infrastructure and extraction of resources. The BC mining industry has made environmental protection a priority during the development, operation and closure phase of mines. Mining regulations in BC are the responsibility of both the federal and provincial governments and regulatory and monitoring processes throughout the life of the mine, including closure, ensure complicity with the environmental objectives of society (*Health, Safety and Reclamation Code for Mines in British Columbia,* 2008; *Mines Act. RSBC,* 1996). Commitments by mining companies during the environmental assessment process also dictate the direction the mine is to go with respect to restoration or reclamation (“The Mining Association of BC” 2013). The BC Mines Act ensures funds are available for restoration/reclamation purposes by way of a bond provided by the mine (“Mines Act” 2014). To this end the mining industry contributes to the scientific community to acquire a better understanding of the effects of mining on the environment, and creating and implementing technology that can help mitigate environmental impacts (“The Mining Association of BC” 2013).

The opening, operation and closure of mines, creates a series of disturbance events over the short-term (years to decades). These disturbances drastically alter the landscape (Vickers et al. 2012). Seeding disturbed sites is undertaken to restore basic ecosystem services, mitigate erosion from wind and water, assist site recovery in terms of the types of desirable species especially when undesirables are nearby, and to help re-introduce species with low dispersal abilities (Baasch et al. 2012).

Restoration of disturbed landscapes, during or after the mining process, is difficult due to the alteration of soil properties by mechanical disruption during topsoil stripping and storage, climactic conditions (Facelli 1991), loss of soil organic matter (Stahl et al. 2003), compaction of soil from heavy equipment (Cavender et al. 2014), and nutrient availability (Asensio et al. 2014). The stripping of topsoil results in soil horizons being mixed and therefore dilution of organic matter occurs (Visser et al. 1984). As well, soil stripping destroys soil macro-aggregates by disrupting roots and fungal communities (Wick et al. 2009b) and these aggregates are slow to recover (Visser et al. 1984). Compaction of the soil by heavy equipment can lead to lowered soil porosity, permeability and moisture holding capacity (Cavender et al. 2014). Climatic conditions are altered through the removal of vegetation resulting in increased evaporation, and erosion by wind and water, and decreasing available shade and plant litter (Facelli 1991, Loydi et al. 2013). Nutrients can be lost when soil layers are mixed and organic matter is diluted. As plants scavenge and uptake nutrients from their surrounding environment, they play a role in topsoil nutrient availability through the accumulation and breakdown of litter (Bradshaw 1997). Therefore, the destruction or altering of a plant community during the life of a mine can result in altered nutrient availability. Restoration is also hindered by the lack of seeds and propagules. The removal of topsoil may at the beginning hold a viable seed bank as well as propagules, but over longer storage periods this may be lost (Rokich et al. 2000, Rivera et al. 2012). Even with the natural community in close vicinity, plants may not have the ability to disperse the distance required to restore the disturbed landscape back to its original state (Suding, Gross & Houseman 2004; Alday *et al.* 2011b).

Thesis Research Objectives

The overall objective of this thesis is to study methods to best restore disturbed semi-arid grasslands in the interior of British Columbia. There are three aims of this thesis. The first two objectives test the suitability of biochar for restoration purposes in the BC interior grasslands. As other scientific studies have shown positive results on plant growth with the use of biochar, I test the effects of biochar on 1) the germination (APPENDIX A); and 2) the growth of a selection of BC's semi-arid native grassland species, presented in chapter 2. The third objective is to test methods of site preparation and seeding techniques using native species in an effort to restore disturbed semi-arid grasslands in the BC interior. In chapter 3, I present a field study on a topsoil stockpile at New Gold's, New Afton Mine, near Kamloops, BC to determine which native species will grow on these disturbed sites and which may be more difficult to establish. The information gained through this study will help to move the field of semi-arid grassland restoration in British Columbia forward.

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CHAPTER 2: THE EFFECTS OF BIOCHAR ON THE GROWTH OF NATIVE SPECIES OF THE BC INTERIOR GRASSLANDS

INTRODUCTION

Mining is an important economic driver worldwide. In British Columbia, Canada it represents billions of dollars in both gross mining revenue and by-products from direct industry expenditures. ("The Mining Association of BC" 2013). However, the building of infrastructure and the extraction of resources creates ecological disturbances of varying degrees. To offset these disturbances the mining industry has made environmental protection a priority in BC. Regulations have also been put in place by federal and provincial governments to ensure compliance with societal expectations throughout the life of the mine including closure (*Health , Safety and Reclamation Code for Mines in British Columbia* 2008; *Mines Act. RSBC* 1996). Legislation requires that disturbed land be returned back to its original productivity level. This is accomplished either through reclamation, defined as ecosystem recovery through the use of species, which may include non-natives and agronomics; or restoration, which is the use of native species to attain a self-sustainable ecosystem. Whether a mine focuses on reclamation or restoration is in part predetermined by the commitments made by the mine during the environmental assessment process ("The Mining Association of BC" 2013).

Mining is often a series of disturbance events, which can drastically alter the landscape (Vickers et al. 2012). Restoration of disturbed landscapes is difficult due to the alteration of soil properties. The loss of structure and change in chemistry can come via mechanical disruption by topsoil stripping, storage (Abdul-Kareem and McRae 1984), loss of soil organic matter (Stahl et al. 2003), compaction of soil by heavy equipment (Cavender et al. 2014), and nutrient availability (Asensio et al. 2014). The stripping of topsoil results in soil horizons being mixed and therefore dilution of organic matter and nutrients occurs (Visser et al. 1984). Soil stripping also has the potential to destroy soil macroaggregates by disrupting roots and fungal communities (Wick et al. 2009b) and these aggregates are slow to recover (Visser et al. 1984). Compaction of the soil by heavy equipment can lead to lowered soil porosity, permeability and moisture holding capacity (Cavender et al. 2014). Climatic conditions are altered through the removal of vegetation resulting in increased evaporation, and erosion by wind and water (Facelli 1991, Brady and Weil 2012). The decreasing available shade and plant litter (Facelli 1991, Loydi et al. 2013) from the loss of vegetation, also affects climate conditions.

Stockpiling topsoil is a way to protect a component of the terrestrial ecosystem when disturbance is imminent. However, the mechanical moving of soil and stockpiling for varying lengths of time, sometimes years, makes it difficult to mitigate potential negative effects to the soil and its properties. Stockpiled topsoil has a tendency to change chemically, biologically and physically over time (Abdul-Kareem and McRae 1984, Kundu and Ghose 1997, Rivera et al. 2012). Some of these changes are due to the mechanized handling of the soil and others because of the anaerobic conditions that may occur within the heaps (Abdul-Kareem and McRae 1984). In semi-arid climates the lack of moisture adds to the level of difficulty in restoring areas where the soil has been damaged (Josa et al. 2012) as soil carbon is slow to build in these environments (Brady and Weil 2012). Therefore, increasing carbon sequestration can result in healthier soils by contributing nutrients and increasing water holding capacity (Gurwick et al. 2013).

As ecosystems differ in their ability to support and sustain flora and fauna it is important to investigate methods which can guide industries in their restoration endeavours. Amending soils is common practice when the goal is to increase primary production during restoration (Shrestha et al. 2010, Tandy et al. 2011, Farrell et al. 2011). Restoration projects have used biosolids, chemical fertilizers, mulch, hay and biochar in an attempt to expedite the restoration of ecosystem services and plant production on damaged landscapes (Morghan and Seastedt 1999, Chan et al. 2007, Ohsowski et al. 2012, Mollard et al. 2014). The addition of organic carbon to soil plays many different roles. It is important to microbial and microfauna communities (Bradshaw 1997, Ohsowski et al. 2012), adds nutrients, and increases the ability of soil to hold water and nutrients (Blumenthal 2008). Addition of carbon has been found to decrease the success of weedy species in tallgrass prairie, mixed-grass prairie, shortgrass steppe and coastal grasslands (Morghan and Seastedt 1999, Paschke et al. 2000, Blumenthal et al. 2013). Whether the addition of carbon to semi-arid grasslands will have the same affect is not known.

Biochar is the bi-product of organic matter heated in a limited oxygen environment at low temperatures (<700°C) for the sole purpose of amending soil (Lehmann and Joseph 2010).

Biochar has been reported to retain nutrients by altering the cation exchange capacity (Liang et al. 2006b) and pH (Novak et al. 2009a) of soil. Biochar has also been recorded to increase adsorption sites for minerals, pesticides and microbial species (Lehmann and Joseph 2010, Beesley et al. 2011). Studies have shown that biochar can have a positive effect on the soil fauna (Lehmann et al. 2011). It has also been suggested that biochar can be used to enhance plant growth by supplying and retaining nutrients in the soil, and improving the physical and biological properties of soil (Glaser et al., 2002; Lehmann & Rondon 2006).

At New Gold’s New Afton mine in the southern interior of British Columbia, Canada, the restoration goal is to return the area to native grassland. My greenhouse study tests the efficacy of using biochar to enhance the growth and establishment rates of native species of the BC interior grasslands, in the restoration of these sites. I expect to see higher above and below ground biomass in the treatment pots with biochar as studies have shown positive effects on plant growth (Glaser et al. 2002, Lehmann and Rondon 2006).

Hypothesis

Biochar will have a positive effect on above and below ground biomass of native flora species indigenous to the interior of British Columbia.

METHODS

Seed Collection

Seeds native to and growing in the Lac du Bois grasslands protected area of the Interior British Columbia grasslands were either collected by hand during the summer of 2012 from populations found throughout the Lac du Bois grasslands (50°47’28.03”N 120°26’30.90”W elevation 450 – 1200m), on land owned by Highland Valley Copper (50°28’41.58”N 120°59’42.08”W elevation 1201m) by Kamloops, British Columbia, or purchased from Pickseeds Ltd., Vancouver, BC (Table 2.1).

To ensure genomic diversity, an attempt was made wherever possible to collect from a number of populations. For example, *Erigeron corymbosus* and *Geum triflorum* seeds were collected across the Lac du Bois grasslands from more than three separate populations.

Oxytropis campestris was difficult to find, so seeds were collected from a large population located at Highland Valley Copper which spanned an area greater than 3 acres. Seeds obtained from Pickseeds were cultivated and harvested in locations across Canada or the United States. All seeds were stored in a chest freezer until planted in January 2013.

Soil and Biochar Collection and Preparation

Stockpiled topsoil was collected from New Gold’s, New Afton mine site (50°38’54.92” N 120°29’59.67” W, elevation 775m) near Kamloops, British Columbia. Stockpiling was done by the mine over a two year period. The removal of the top layer of soil was accomplished by large machinery stripping the soil and moving it onto stockpiles. For this study, topsoil was obtained from one of these piles. All further work was completed at the Thompson Rivers University (TRU) Research Greenhouse between November 23, 2012 and July 30, 2013.

The topsoil was sifted to remove large stones and break up large soil clumps using a <2.6 mm soil sifter. Once sifted, the topsoil was stored in a 100 gallon black rubber water trough inside the header house of the greenhouse. Biochar was obtained from BC Biocarbon in Prince George, British Columbia. The biochar was produced from pine and spruce bark chips and wood (hog fuel). The hog fuel was processed at a pyrolysis temperature of approximately 550°C and then stored at room temperature after production. The biochar was sifted to <5 mm to remove large chunks of wood or char before being weighed and mixed with the topsoil.

Treatments were designed as percent volume by weight (Revell, Maguire, & Agblevor, 2012). To calculate the volume needed, the weight of a specified volume of biochar and soil was determined. Ten 60ml samples each of biochar, topsoil, sand, and topsoil + sand (50/50) were measured and placed in pre-dried, pre-weighed, brown paper bags. The measured samples of biochar and soil mediums were then dried in a drying oven for 72 hours at 80°C before being weighed to 0.1 mg on a Fisher Scientific analytical scale.

Samples of both the topsoil and the biochar were sent to the BC Ministry of Environment, Soil Chemistry Analysis Environmental Sustainability and Strategic Policy Division. The CEC at soil pH (Barium chloride extraction), total C, N and S (combustions elemental analysis), and total metallic elements (microwave digestion) were determined (Table 2.2).

Table 2.1: List of native species (Hitchcock and Cronquest 1990) used in the germination and growth study for New Gold, New Afton Mine. Common names and functional group (forb or graminoid) for each species has been included. Species have also been grouped to three seed sizes. First Nations Secwepemc names have been added where known. Species highlighted in bold were used in the germination experiment. The symbol "-" represents missing seed weight data or in the case of days to germinate, the seeds failed to germinate.

Species	Secwepemc	Common name	Function	Seed size	Days to Germinate
Achillea millefolium	**Qets'uye7ellp**	**White yarrow**	**Forb**	**<1mg**	**5-7**
Achnatherum hymenoides		Indian rice grass	Grass	>3mg	7-10
*Allium cernuum**		Nodding onion	Forb	>3mg	14-21
*Antennaria rosea**		Rose pussytoes	Forb	<1mg	10-18
*Artemisia tridentata**		Big sagebrush	Forb	-	7-12
*Astragalus purshii**		Woollypod	Forb	>3mg	-
Balsamorhiza sagittata	Ts'elqenupye7	Arrowleaf	Forb	>3mg	21+
*Campanula rotundifolia**		Harebell	Forb	<1mg	10-18
*Castilleja thompsonii**		Thompson's	Forb	<1mg	10-14
Delphinium nuttallianum		Larkspur	Forb	<1mg	-
Elymus glaucus		**Blue wildrye**	**Grass**	**>3mg**	**4-7**
Elymus trachycaulus		**Slender wheatgrass**	**Grass**	**>3mg**	**4-7**
*Ericameria nauseosa**		Rabbitbrush	Forb	-	7-12
*Erigeron compositus**		Cutleaf daisy	Forb	<1mg	7-10
Erigeron corymbosus*		**Longleaf fleabane**	**Forb**	**<1mg**	**7-10**
*Erigeron filifolius**		Threadleaf fleabane	Forb	<1mg	7-10
Festuca campestris		**Rough fescue**	**Grass**	**<2mg**	**4-7**
Festuca idahoensis		Idaho fescue	Grass	<2mg	4-7

Species	Secwepemc	Common name	Function	Seed size	Days to Germinate
Festuca saximontana		Rocky mountain	Grass	<1mg	4-7
Fritillaria pudica		Yellow bell	Forb	<2mg	-
Gaillardia aristata	**Sqlelten re**	**Common gaillardia**	**Forb**	**>3mg**	**5-10**
Geum triflorum*		**Old man's whiskers**	**Forb**	**<2mg**	**6-12**
Hesperostipa comata		**Needle and thread**	**Grass**	**>3mg**	**7-10**
*Heuchera cylindrica**		Roundleaf alumroot	Forb	<1mg	10-14
Koeleria macrantha		June grass	Grass	<1mg	7-10
Linum perenne L.		Blue flax	Forb	<2mg	7-12
*Mentzelia Laevicaulis**		Blazing star	Forb	<1mg	12-16
Oxytropis campestris*		**Field locoweed**	**Forb**	**<2mg**	**12-18**
Poa juncifolia		Alkali bluegrass	Grass	<1mg	5-10
Poa secunda (sandbergii)		Sandberg bluegrass	Grass	<1mg	5-10
*Potentilla gracilis**		Slender cinquefoil	Forb	<1mg	7-12
Pseudoroegneria spicatum		**Bluebunch**	**Grass**	**>3mg**	**5-10**
*Rhinanthus minor**		Yellow rattle	Forb	<2mg	-
Sporobolus cryptandrus		Sand dropseed	Grass	<1mg	7-10

* Hand-picked

All other seeds were purchased from Pickseed, Vancouver, BC with the exception of *Fritillaria pudica* and *Delphinium nuttallianum* which were purchased from Quality Seeds, Kamloops, BC

Table 2.2: Analysis of stockpiled topsoil (T1-T3) collected from the top 5cm of the restoration study site at New Gold’s New Afton Mine in the fall of 2012. Biochar analysis of char made from pine and spruce hog fuel at a pyrolysis temperature of 550°C.

	Element		Sample T1	Sample T2	Sample T3	Biochar
Microwave Digestion / ICP "Totals"	Al	%	2.336	2.440	2.334	0.298
	B	mg/Kg	40.5	33.9	42.8	20.5
	Ca	%	4.594	4.411	4.549	2.002
	Cu	mg/Kg	95.0	150.8	123.9	37.8
	Fe	%	3.203	3.441	3.194	0.658
	K	%	0.453	0.443	0.495	0.383
	Mg	%	2.211	1.945	2.356	0.203
	Mn	mg/Kg	773	792	773	545
	Na	%	0.362	0.324	0.401	0.035
	P	%	0.106	0.107	0.106	0.059
	S	%	0.186	0.164	0.200	0.053
	Zn	mg/Kg	65.8	68.9	66.4	314.6
Total N, C and S	N	%	0.133	0.114	0.140	0.142
	C	%	2.80	2.53	2.84	75.51
	S	%	0.179	0.133	0.193	0.064
Exchangeable Cations and Effective CEC (0.1 M Barium Chloride)	Al	Cmol + /Kg	0.031	0.001	0.003	0.152
	Ca	Cmol + /Kg	8.78	10.74	9.69	11.41
	Fe	Cmol + /Kg	0.009	< 0.001	< 0.001	0.002
	K	Cmol + /Kg	1.451	1.458	1.771	2.525
	Mg	Cmol + /Kg	10.05	10.84	11.62	1.89
	Mn	Cmol + /Kg	< 0.001	< 0.001	< 0.001	0.018
	Na	Cmol + /Kg	5.543	3.754	7.031	0.394
	CEC	Cmol + /Kg	25.86	26.80	30.12	16.39

Experimental Design

The experiment was designed as a randomized block design, located in the same greenhouse pod, with 10 replications. One treatment (biochar or no biochar) was studied on 30 native grassland species including forbs, graminoids and woody species (n=600) (Table

2.2). All pots were labelled and filled with either: 1) topsoil and sand; or 2) the topsoil, sand and biochar mix. Sand was mixed with the topsoil to mitigate compaction within the pots throughout the study period.

Stockpiled topsoil collected from New Afton Mine was sieved to <1 cm in diameter to remove large gravel. The biochar was crushed and then sieved to achieve a diameter of <5mm. The topsoil was mixed with sand at a 50/50 ratio. The biochar was then mixed with the soil-sand mixture at a ratio of 10 g/L. Both treatment mixtures were stored in large rubber cattle troughs and mixed daily for 4 weeks. Landscape fabric was placed in the bottom of 1 L pots to ensure soil did not escape through the drainage holes. Pots were watered to saturation on the day of set up and were kept moist for 2 weeks before transplanting seedlings.

Graminoid seeds were planted in petri dishes with sand and kept damp until germination. The seedlings were planted when roots were ~3-5 cm long. A hole was made in the soil and the seedling was planted to depth of root. Care was taken to ensure plants chosen for transplanting were of similar size. At the time of transplanting, the seedlings were watered with 80 ml of Plant Prod fertilizer (20:20:20) at a ratio of 3 g/L (APPENDIX B). Two species were difficult to transplant (*Achnatherum hymenoides* and *Elymus glaucus*) and hence were direct seeded into the pots. One week after germination the seedlings were thinned to one plant, ensuring each pot had a seedling of similar size. Forbs were also seeded directly into the pots as they were difficult to transplant and establishment rates were poor. It was noted that pots with biochar appeared to have better transplanting success for some species, suggesting the need for further study. The forb seedlings were thinned and every attempt was made to make sure seedlings for each replicate and treatment were the same size when thinned to one plant.

Pots were watered daily to ensure saturation. Some areas of the greenhouse were wetter than others, due to the misting system. Pots located outside of the “wet zone” were checked twice daily to ensure moisture levels stayed consistent throughout the greenhouse. Watering occurred in the mornings and evenings each day. Once a week, all plants were fertilized with a 20:20:20 fertilizer (3 g/L) (Figure 2.1). Fertilizing started one week after germination for those species that were directly sowed into pots. Each pot received 100 mL of fertilizer treated water in the morning watering.

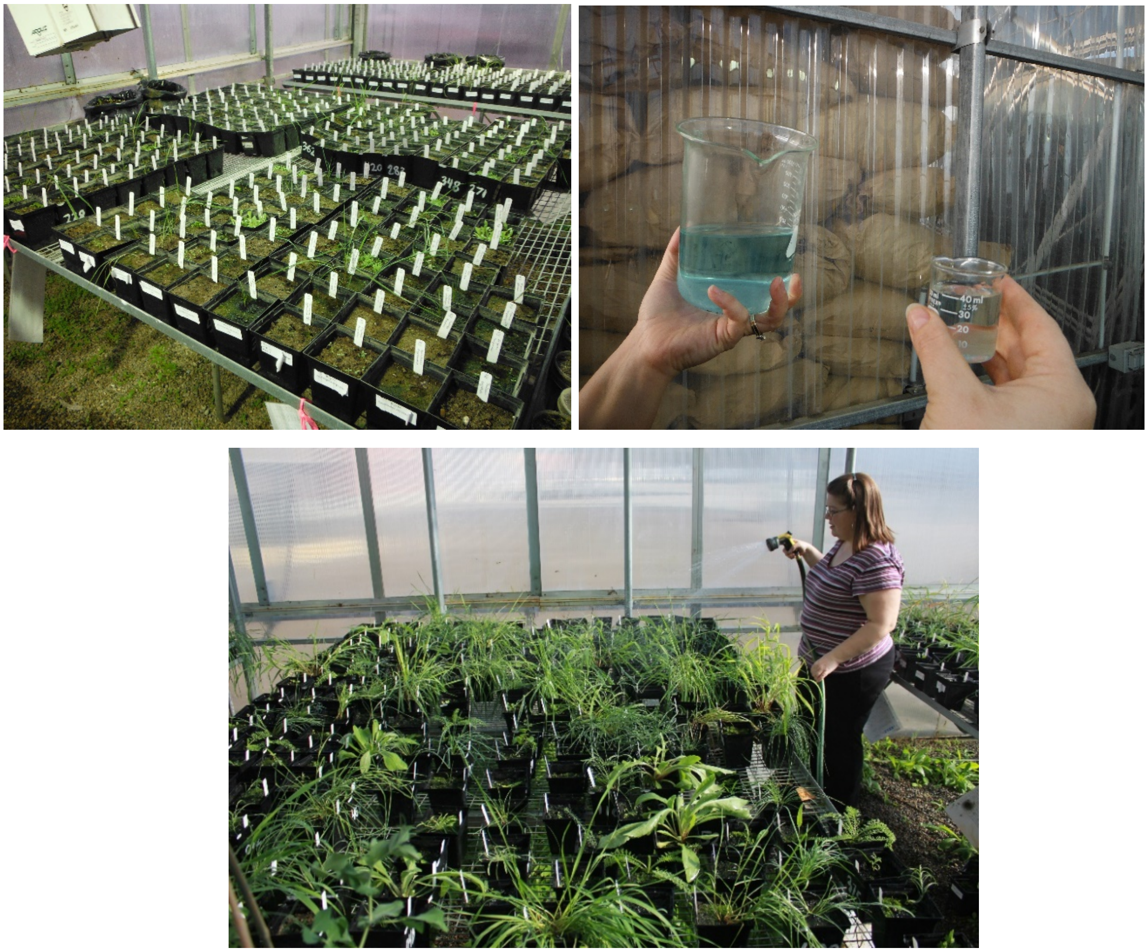

Figure 2.1: Growth experiment of 30 native species from the British Columbia interior grasslands. Treatments consisted of topsoil + Sand (50/50 mixture) with or without 15 t/ha biochar (volume by volume). Top left picture shows six of the 10 replicates (randomized block design). Top right picture shows method of fertilization to ensure all pots received the same amount of fertilizer each week. Bottom picture shows daily watering of pots.

Plants were harvested after 89 days of growth (Figure 2.2). Above ground biomass was removed at soil level and placed in labelled paper bags before being dried. Below ground biomass was washed of all soil medium and also placed in labelled pre-weighed bags. All samples were dried in a constant temperature forced air Yamato drying oven at 70° C for 48 hours. Once dried the samples were weighed on a Fisher Scientific analytical scale.

Figure 2.2: Harvesting at 89 days growth. Roots were washed of all soil medium (top left and right) before removing the above ground biomass from the below ground biomass at the crown of the plant (bottom left and right).

Statistical Analysis

Data for the growth experiment were analyzed using R Studio version 2.15.3 (2013). The analysis for biochar on above and below ground growth was not normally distributed and transformation to normalize data was unsuccessful. Data was thus analyzed using the nonparametric Kruskal-Wallis test. All data were tested for significance at $p<0.05$.

RESULTS

Biochar did not have a positive or negative effect on the above or below ground dry biomass of the 30 semi-arid grassland species studied (Table 2.3). Further separation of the species into functional groups also did not reveal any effect of biochar within the forb or graminoid groups.

Table 2.3: Results from growth experiment using biochar on native species from the BC interior grasslands. Results are from a Kruskal-Wallis test on above and below ground dry biomass (n=600 for both above and below ground dry biomass data). Growth experiment factors consisted of biochar (15t/ha volume by weight) or no biochar. Significance was set at $p \leq 0.05$.

	Above ground biomass			Below ground biomass		
	χ^2	df	p-value	χ^2	df	p-value
All species	0.4662	1	0.4947	0.0020	1	0.9609
Graminoids	0.0205	1	0.8861	0.7551	1	0.3849
Forbs	0.8731	1	0.3501	0.5570	1	0.4555

DISCUSSION

Studies have shown biochar soil amendments lead to enhanced plant growth (Major et al. 2010, Graber et al. 2010, Uzoma et al. 2011). The results of my study contradict those of previous studies showing no increased above or below ground biomass with the addition of biochar. The study was relatively short-term (<3 months) and the pots used were small (<1L) in size. It is plausible that the effects of biochar have a temporal factor. Given longer growing times, and larger pots, differences may become evident both above and below ground. In many cases the grasses outgrew the pots and the roots had little room to expand. Also, many grasses went to seed and dormancy during the trial. Larger pots or field trials over a number of years may reveal more differences in biomass between biochar treated and untreated soils given more time and space to grow.

Field studies that have revealed large growth increases with biochar have been longer term studies (>3 years) (Major et al. 2010), other greenhouse experiments planted within plots giving greater growing space (Uzoma et al. 2011) or much larger plots in the field (Olmo et al. 2014). Major *et al.* (2010) studied the effects of two ratios of biochar (8 t/ha and 20 t/ha) on the growth and nutrient uptake of maize. They found little difference in the first year between treatments, but in the second, third and fourth years observed an increase of 19%, 15% and 71% respectively for the 8 t/ha treatments; and 28%, 30% and 140% respectively for the 20 t/ha biochar treatment. Uzoma *et al.* (2011) tested the effects of cow manure biochar in a greenhouse experiment using in-ground plots measuring 0.26 m x 0.21 m and biochar mixed into the top 15 cm of sandy soil. After 55 days the 15t/ha ratio of biochar had a growth rate (number of leaves and height of plant) of ~65% more than that of the control group. The 15t/ha treatment also resulted in a higher grain yield (150%). Olmo *et al.* (2014) looked at the effects of olive-tree biochar on wheat growth and yield in plots measuring 15 m^2. This study found that at the first sampling date (36 days) there was little difference in growth between biochar and no biochar. However after 187 days significant differences were seen between the two treatments. For example, above ground biomass was ~1345 g/m^2 and spike density was ~714 g/m^2 in biochar treated soils and in the control treatment aboveground biomass was ~1115 g/m^2 and spike density was ~563 g/m^2.

Despite the results I received, further research should be carried out using longer term trials including the use of larger pots to allow for greater root growth. It is plausible that my study lacked the time and root space needed to obtain consistent results with other studies on the effects of biochar on the growth of semi-arid grassland species. It is also possible the feedstock used to make the biochar was not the best type for grassland restoration in the BC interior. For future study, in addition to large-scale, long-term field studies on native species, studies should include the effects of biochar on invasive species. As well, it is important to study biochar made from different feedstocks in the soil types to be restored as effects may differ with biochar type.

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CHAPTER 3: THE EFFECT OF SITE PREPARATION ON THE ESTABLISHMENT OF NATIVE GRASSLAND SPECIES IN SOUTHERN INTERIOR, BC

INTRODUCTION

Mining provides essential resources and economic growth; however, it also creates highly disturbed areas through the building of its infrastructure and the mining process itself. There are often a series of disturbance events through opening, operation and closure that occur over the short-term, and these disturbances alter the landscape (Vickers et al. 2012). To mitigate the damage caused, the mining industry in general has made great progress in environmental protection as a priority during the development, operation and closure phase of mines. For example, in British Columbia mining regulation and mine closure are governed by the BC Mines Act (*Mines Act. RSBC* 1996, *Health , Safety and Reclamation Code for Mines in British Columbia* 2008).

The Mines Act and the “Code” in British Columbia specify that reclamation must satisfy the requirements of the Chief Inspector (*Mines Act. RSBC* 1996, *Health , Safety and Reclamation Code for Mines in British Columbia* 2008). Because the legislation is vague and subject to interpretation (both by the mining companies and the Inspectors) there has been variability in goals and measures of success. Historically, the goals were set for productivity because it was easy to measure. The current “code” (10.7.5) expresses a goal for equivalent land capability, which is a vague and challenging reclamation target to achieve.

Reclamation and restoration are two different targets. Reclamation is the process of returning a disturbed site back to its pre-disturbance productivity level using a combination of species including non-native agronomics. Restoration, on the other hand, is the process of returning a site back to its natural state in which the ecosystem becomes self-sustainable once again (Alday et al. 2011a). To attain either of these goals seeding is often undertaken to mitigate erosion from wind and water, and to assist site recovery in terms of the types of desirable species (Baasch et al. 2012). Historically, industries used agronomic species for reclamation because of their ability to colonize quickly thus reducing erosion and making the area aesthetically pleasing (Carrick and Krüger 2007, Bochet et al. 2010b). However, agronomic species can become invasive and thus reduce species richness and diversity within nearby native communities (Christian and Wilson 1999). With restoration, the addition of native seed has been shown to affect the path and speed of succession (Martin and Wilsey 2006, Prach and Hobbs 2008, Baasch et al. 2012). Research in this area is important as ecosystems differ and methods of restoration must be altered to match the biotic and abiotic factors and stresses of the area (e.g. arid grassland versus forested wetland landscape). As degraded sites are in an altered state, the impact restoration will have on the path of succession is unknown and hard to predict (Suding et al. 2004), thus research should be an integral part of a mine's restoration strategy.

Grasslands present a unique set of problems when it comes to restoration. Restoring grasslands in semi-arid systems is difficult due to environmental and economic limitations (Prach and Hobbs 2008). In BC, the grasslands are predominantly found in the 'rain-shadow' east of the Coast and Cascade Mountains, where the climate is dry and summers are hot (Wikeem and Wikeem 2004, "Grasslands Conservation Council" 2012). Low precipitation rates in grasslands can reduce germination, establishment and growth (Josa et al. 2012). Adding a disturbance stress can reduce the availability of nutrients (Bendfeldt et al. 2001), disrupt the microbial community (Johnson et al. 1991, Wanner and Dunger 2001), increase compaction where heavy equipment is used thus decreasing water and root penetration (Burke 2007, Bochet et al. 2010a), and increase the potential for invasion by exotic species (Yurkonis et al. 2008, 2012). Microclimates created by topography as well as plant biomass, including litter, play an important role in the amount of sun or shade an area receives, the intensity of wind experienced, the amount of precipitation that can be sequestered and the amount of evaporation and transpiration that occurs at a site (Chambers and MacMahon 1994). Economically the lack of or low availability of seed and/or high cost of seed (Rowe 2010) can make restoration goals difficult to obtain. Together these factors make finding techniques to ensure successful restoration challenging.

In an effort to overcome the unique challenges of grassland restoration, different seeding techniques have been used (Bernstein et al. 2014). Raking and tilling have been used in an effort to increase the germination and establishment success in grassland restoration (Wilson and Tilman 1993, Wilson and Gerry 1995, Pywell et al. 2002, Carrick and Krüger 2007, Foster et al. 2007, Standish and Hobbs 2009). Wilson & Gerry (1995) found that low disturbance and high disturbance tilling resulted in higher densities of native species as opposed to no tilling or medium disturbance tilling. Although tilling can reduce soil compaction (Burke 2003) and increase microclimates by roughening the soil surface (FLH Western Federal Lands Highway Division 2007), whether it decreases or increases invasion by exotics is controversial as studies have shown both outcomes (Wilson and Gerry 1995, Montalvo et al. 2002, Cosgriff et al. 2004, Kiehl et al. 2010).

Litter and hydro-slurry have been used to reduce erosion, maintain moisture levels, add nutrients and increase germination and seedling establishment (Matesanz et al. 2006, Dunifon et al. 2011, Oliveira et al. 2012, Loydi et al. 2013). A meta-analysis on the effects of litter on seedling emergence by Loydi et al. (2013), revealed seedling emergence in dry grasslands was affected by the amount of litter. Heavier amounts of litter can act as an obstacle for seedlings trying to access light. However, litter can also have an effect on soil temperature and moisture by creating shade and reducing evaporation. Hydro-slurry, which may create a similar environment to plant litter, is often used for re-vegetating slopes in an attempt to reduce erosion (Matesanz et al. 2006), increase moisture availability and increase germination. As some studies have found little value to hydro-seeding in semi-arid environments the writer feels the benefit to hydro-seeding is somewhat controversial.

Studies by Matesanz *et al.* (2006) and Dunifon *et al.* (2011) indicated hydro-seeding native species on road-side slopes in a Mediterranean semi-arid environment resulted in poor seedling establishment. However, a study by Tormo, Bochet & Garcıa-Fayos (2007) successfully re-established road banks with hydro-seeded native species. I expect an increase in germination and establishment with hydro-seeding due to the experimental site’s flat topography and the addition of water through bi-weekly watering. I also expect to see increased establishment on raked sites as has been seen in previous studies (Wilson and Gerry 1995, Montalvo et al. 2002). Many studies have shown that sowing native species results in increased germination and establishment of these species as well as increased species richness and diversity over one or more years (Montalvo et al. 2002, Martin and Wilsey 2006, Martínez-Ruiz et al. 2007, Yurkonis et al. 2008, Dornbush and Wilsey 2010, Kiehl et al. 2010). As the BC Interior grasslands are water limited, using species adapted to the area should result in increased native vegetative cover and increased species richness and diversity.

Hypotheses

1) Hydro-seeding will result in increased germination and establishment rates for native species due to its ability to reduce erosion and increase moisture levels.

2) Raking will increase germination and establishment of native flora indigenous to the interior of BC, but will also increase invasion by exotics.

3) Seeding native grassland species will result in higher species richness and diversity compared to site left to natural processes.

METHODS

Site Description

The study took place at New Gold's New Afton Mine site west of Kamloops, British Columbia (50°38'54.92" N 120°29'59.67" W, elevation 775m). The New Afton Mine is an underground, working copper-gold mine situated on a historical open pit. The mine is located in the Ponderosa Pine and Interior Douglas-fir biogeoclimatic zone and the surrounding grasslands are a northern extension of the Pacific Northwest Bunchgrass grasslands (BC Ministry of Forests 2014). This area has a short, warm summer season (May – September) with average temperatures ranging from 8°C to 29°C respectively. Winter mean annual temperatures range from -6°C to 5.6°C. The average yearly precipitation is ~278mm with 81% of the moisture coming as rainfall and 19% coming as snowfall ("Climate Data, Environment Canada" 2014).

The stockpiled topsoil was classified as chernozemic. The removal and stockpiling process resulted in some mixing of the A and B horizons. The stockpile was young (<2 yrs) with the oldest soils at the bottom. Chemical make-up of the stockpiled topsoil can be found in Table 3.1.

Table 3.1: Analysis of stockpiled topsoil (T1-T3) collected from the top 5cm of the restoration study site at New Gold's New Afton Mine in the fall of 2012.

	Element		Sample T1	Sample T2	Sample T3
Microwave Digestion / ICP "Totals"	Al	%	2.336	2.440	2.334
	B	mg/Kg	40.5	33.9	42.8
	Ca	%	4.594	4.411	4.549
	Cu	mg/Kg	95.0	150.8	123.9
	Fe	%	3.203	3.441	3.194
	K	%	0.453	0.443	0.495
	Mg	%	2.211	1.945	2.356
	Mn	mg/Kg	773	792	773
	Na	%	0.362	0.324	0.401
	P	%	0.106	0.107	0.106
	S	%	0.186	0.164	0.200
	Zn	mg/Kg	65.8	68.9	66.4
Total N, C and S	N	%	0.133	0.114	0.140
	C	%	2.80	2.53	2.84
	S	%	0.179	0.133	0.193
Exchangeable Cations and Effective CEC (0.1 M Barium Chloride)	Al	Cmol + /Kg	0.031	0.001	0.003
	Ca	Cmol + /Kg	8.78	10.74	9.69
	Fe	Cmol + /Kg	0.009	< 0.001	< 0.001
	K	Cmol + /Kg	1.451	1.458	1.771
	Mg	Cmol + /Kg	10.05	10.84	11.62
	Mn	Cmol + /Kg	< 0.001	< 0.001	< 0.001
	Na	Cmol + /Kg	5.543	3.754	7.031
	CEC	Cmol + /Kg	25.86	26.80	30.12

Experimental Design

Plant species selected for sowing were chosen based on their presence in the Interior grasslands of British Columbia and their cultural importance to the local First Nations (TK'emlups and Skeetchestn) (Table 3.2) as agreed upon in the assessment process. Seeds were either handpicked or sourced from local seed companies. For those species which were handpicked, the populations were followed through the 2012 summer season and harvested once seeds had set and matured. Seeds were collected from a number of populations whenever possible. Exceptions were *Mentzelia laevicaulis* and *Oxytropis campestris*. *M. laevicaulis* was collected from a single population found on the New Afton Mine site and *O. campestris* was picked from a single population found at Teck Resources' Highland Valley Copper Mine site. After collection, all seeds were sealed in plastic ziploc bags and stored in a chest freezer.

Table 3.2: List of species used in New Gold, New Afton Mine field study. List includes where seeds were purchased or when hand-picked where the seed populations were located. Species have also been grouped into functional groups of forbs and graminoids and First Nations Secwepemc names have been added where known.

Species	Secwepemc	Common	Type	Source
Achnatherum hymenoides		Indian rice grass	Grass	Pickseed*
Elymus glaucus		Blue wildrye	Grass	Pickseed*
Elymus trachycaulus		Slender wheatgrass	Grass	Pickseed*
Festuca campestris		Rough fescue	Grass	Pickseed*
Festuca idahoensis		Idaho fescue	Grass	Pickseed*
Festuca saximontana		Rocky mountain fescue	Grass	Pickseed*
Hespirostipa comata		Needle-and-thread grass	Grass	Pickseed*
Koeleria macrantha		June grass	Grass	Pickseed*
Poa juncifolia		Alkali bluegrass	Grass	Pickseed*
Poa secunda		Sandberg bluegrass	Grass	Pickseed*
Pseudoroegneria spicata		Blue bunch wheatgrass	Grass	Pickseed*
Sporobolus cryptandrus		Sand dropseed	Grass	Pickseed*
Achillea millifolium	qets’uye7ellp (W)	Yarrow	Forb	Pickseed*
Antennaria rosea /umbrinella		Pussytoes (rose/umber)	Forb	Lac du Bois
Astragalus purshii		Woollypod milkvetch	Forb	Lac du Bois
Balsamorhiza sagittata	Ts’elqenupye7	Arrow-leaved balsamroot	Forb	Pickseed*
Campanula rotundifolia		Harebell	Forb	Lac du Bois
Delphinium nuttallianum		Larkspur	Forb	Quality Seeds
Erigeron compositus		Cutleaf fleabane	Forb	Lac du Bois

Species	Secwepemc	Common	Type	Source
Erigeron filifolius		Threadleaf fleabane	Forb	Lac du Bois
Fritillaria pudica		Yellow bells	Forb	Quality Seeds
Gaillardia aristata	sqlelten re ckwtut’stens	Brown-eyed susan	Forb	Pickseed*
Mentzelia laevicaulis		Blazing star	Forb	New Afton Mine
Oxytropis campestris		Field locoweed	Forb	Highland Valley Copper, Logan Lake, BC

* Purchased from Pickseed, Vancouver, BC. Location of seed cultivation unknown.

A topsoil stockpile located north of the tailings pond at New Afton Mine was levelled and a grid of 80 plots was created on the east end in October 2012 (Figure 3.1). Each plot measured 4 m^2 with a half meter between each plot to allow for movement between the treatments for watering and assessment. Each row (replicate) had 8 treatments; four soil preparation factors: 1) raking; 2) hydro-slurry; 3) hydro-slurry x raking; and 4) a control where no soil preparation was completed; and each of these factors had a seeded and unseeded component (4 x 2 x 10; n=80). Treatments were randomized within each replicate using a computer generated randomization plan (random.org) ("Random.org" 2012).

In the fall of 2012 seed packets were prepared for fall planting. Envelopes were labelled and filled with 45 ml of sand as a carrying agent, for each treatment (80 in total). Plots were seeded with 1200 seeds/m^2 (Fraser and Grime 1999). Twelve forb and 12 graminoid species were used, and 200 seeds per species was counted (24 species x 200 seeds = 4800 seeds/plot). In October 2012, when the grid was set up, it was noted that the stockpile had areas that were compact. To reduce the effect of compaction on raked treatment plots, a shovel was used to loosen the soil, and soil from the edge of the stockpile was added to help simulate a tilled/raked treatment. Three 12 L buckets of topsoil from the edge of the same stockpile were added to each of the raking treatments to maintain consistency throughout the study grid.

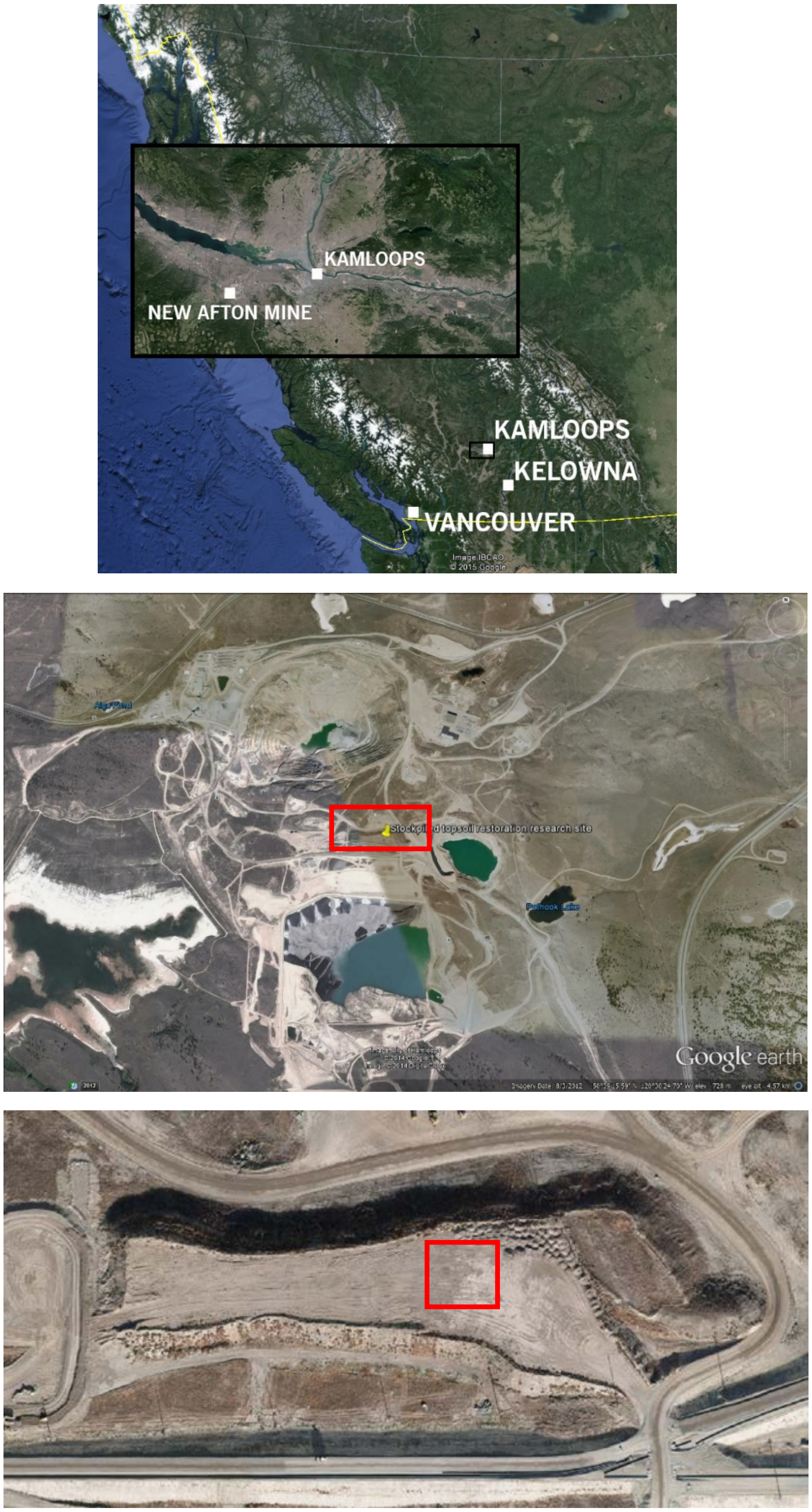

Figure 3.1: The study site was located in the British Columbia Interior west of Kamloops (top figure) at New Gold's New Afton Mine (centre figure). Yellow pin indicates location of stockpiled topsoil on the New Afton Mine site. Close up of the stockpile (bottom figure) shows the location of the study grid on the east end of stockpile.

Seeding took place in November 2012 when temperatures were low enough (<10°C) to ensure early germination would not occur (Martínez-Ruiz et al. 2007). Seeds were hand-broadcast on treatment plots to be seeded (including sand only control packets) except those designated for hydro-slurry. Hand-seeding was conducted by only two people to reduce bias (Figure 3. 2). For hydro-seeded plots, hydro-slurry was mixed in a large hydroseeder drum with mixing paddles. The formula used was the same used by the mine to hydro-seed embankments with an angronomic seed mix. Two bags of ecofibre premium wood fibre mulch (22.68 kg) + 2.25 L premium super tackifier + 18.1 kg jet spray fibre mulch with poly fibre was mixed with water to fill the drum to 550 gallons and was thoroughly mixed. Seeds were mixed into the hydro-slurry by filling 2 – 12 L buckets and then adding half of the seed mixture into each bucket. To ensure even mixing of the seeds in the slurry, a stick was used to stir the seed mix into the slurry. Control packets contained only sand and were mixed into the hydro-slurry, ½ into each bucket to stay consistent with the seeded packages (Figure 3.3). The hydro-seed mixture was spread over the plots by pouring the two buckets evenly over the treatment area. All control plots were hydro-slurried first to ensure no contamination occurred between control sites and seeded treatment sites (Figure 3.4). In the spring of 2013, plots were watered with 4mm of water twice a week beginning in May using watering cans with disperser spouts (Figure 3.5). Watering continued until the June rains began and then plots were only watered on those watering days where there was no rain. Plots were watered until the water pooled on the soil surface. This moisture was allowed to seep through the soil before the remaining water was added. Plot assessments were carried out the second week of July 2013. A 1 m^2 grid was placed in the center of each treatment plot and all species within the grid were counted and recorded.

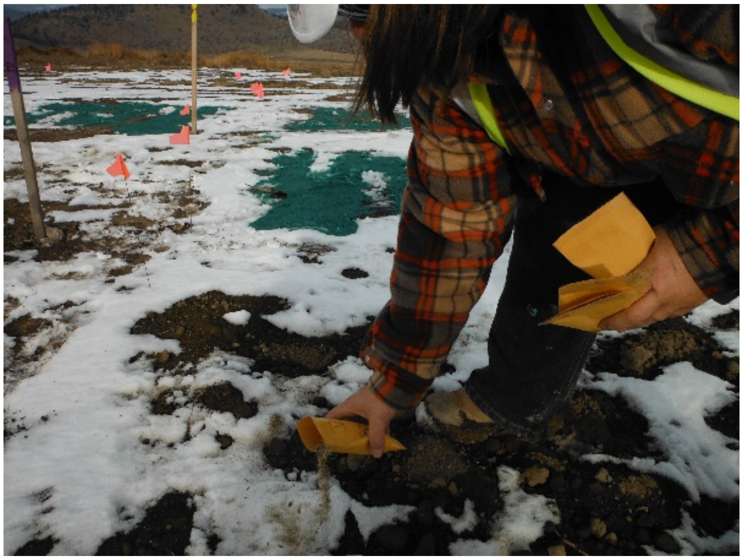

Figure 3.2: Seeding sites on stockpiled topsoil at New Gold's New Afton Mine Site. Plots were seeded the middle of November 2012 to ensure temperatures remained below 10°C to ensure no seed germination occurred before winter set in. Control sites were seeded with packages containing the same carrier sand as the packages with seed

Figure 3.3: Hydro-seeding sites on stockpiled topsoil at New Gold's New Afton Mine Site. Buckets were marked at the 12 L line and then filled with hydro-slurry (left). In preparing the buckets for spreading, ½ of the seed packet (control seed packages with no seed and packages with seed) were emptied into each bucket and stirred to mix thoroughly before being spread on the appropriate treatment plot (right).

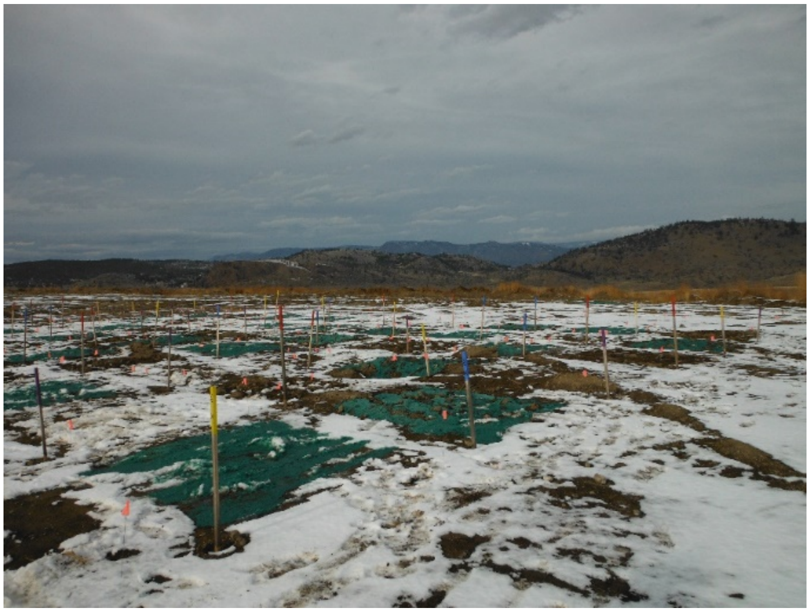

Figure 3.4: Stockpiled topsoil at New Gold's New Afton Mine site after the grid was seeded. Treatment plots were either raked, hydro-slurried, raked x hydro-slurry, or had no manipulation and each of these factors was either with or without seed. Seeding took place in November 2012.

Figure 3.5: May and June watering of site preparation and seeding study at New Gold’s New Afton Mine site. Watering was completed by hand using watering cans with dispenser heads (left). All plots were watered with 4mm/m^2 twice a week. The right figure shows a plot with standing water which was allowed to seep into the soil before more water was applied.

Statistical Analysis

Statistical analysis of vegetation count data was conducted using R Studio (R version 2.15.3; 2012 R Foundation for Statistical Computing). A Filgner test for homogeneity of variances was completed for all data sets. Data were square root transformed to satisfy assumptions of a normal distribution, and a three-way analysis of variance (ANOVA) was used to determine differences between treatments and a Tukey post hoc analysis was conducted when there was a significant statistical difference ($p \leq 0.05$) to determine interactions between factors.

RESULTS

Both non-native and native species as groups responded similarly to the raking and hydro-seeding treatments (Table 3.3; Figure 3.6). Raking alone with no added seed did little to increase the number of native species. Seeding natives increased the number of seedlings by 1.5x compared to the unseeded control site. When raking and seeding were combined an interaction was seen resulting in an increase in the number of native seedlings. An average of 16 or 4x more seedlings were counted compared to the seeded control site (Figure 3.6). Non-natives, on raked sites, had an average of 156 plants, approximately 2.5x more than the control sites. Sites with hydro-seeding resulted in a 50% decrease in natives compared to the control site and a 34% decrease in non-natives on the hydro-seeded sites compared to the control seeded sites. Although there was an interaction in the hydro-seed x raked treatment for natives compared to the unseeded counterpart, the hydro-seed x raked treatment was significantly less than the raked x seeded sites by 56%. There was a reduced number of non-natives on the hydro-seeded x raked sites, but not significantly different from the raked sites.

Table 3.3: Results from 3-way ANOVAs, raking (raking/no raking), hydro-slurry (hydro-slurry/no hydro-slurry) and seeding (Seed/No Seed) on numbers of native and non-native species on stockpiled topsoil at New Gold's New Afton Mine Site (n=80). Results were also compiled for Shannon diversity and species richness. Columns labelled RxH, RxS, HxS and RxHxS represent interactions between raking (R), hydro-slurry (H), and seed (S). Confidence level was set at 0.95 ($p \leq 0.05$).

	Rake F(P-value)	**Hydro-slurry F(P-value)**	**Seed F(P-value)**	**RxH F(P-value)**	**RxS F(P-value)**	**HxS F(P-value)**	**RxHxS F(P-value)**
Native plants	**21.21 (1.73e-05)**	0.65 (0.42)	**66.80 (7.29e12)**	0.51 (0.48)	**10.09 (0.00)**	**3.95 (0.05)**	0.94 (0.34)
Non-native plants	**31.69 (3.27e-07)**	2.63 (0.11)	0.28 (0.60)	0.34 (0.56)	0.36 (0.55)	**3.97 (0.05)**	0.07 (0.79)
Native graminoid	**14.05 (0.00)**	2.00 (0.16)	**36.72 (5.67e-08)**	**4.16 (0.05)**	**20.00 (2.83e-05)**	**4.59 (0.04)**	0.45 (0.51)
Non-native graminoid	0.29 (0.59)	0.81 (0.37)	0.68 (0.41)	0.01 (0.93)	1.47 (0.23)	0.01 (0.92)	0.42 (0.52)
Native forb	**17.98 (6.53e-05)**	0.33 (0.56)	**58.53 (6.87e-11)**	0.04 (0.84)	**5.83 (0.02)**	2.84 (0.10)	0.67 (0.42)
Non-native forb	**32.85 (2.16-e-07)**	2.90 (0.09)*	0.27 (0.61)	0.31 (0.58)	0.28 (0.60)	3.85 (0.05)*	0.14 (0.71)
Shannon diversity index	0.45 (0.50)	**4.64 (0.03)**	**11.59 (0.00)**	2.48 (0.12)	**5.20 (0.03)**	0.28 (0.60)	0.25 (0.62)
Species richness	**5.52 (0.02)**	0.05 (0.82)	**31.27 (3.79e-07)**	0.61 (0.44)	**7.82 (0.00)**	0.20 (0.66)	0.61 (0.44)

Non-native and native groupings were arranged into functional groupings of forbs and graminoids. The number of forb seedlings, both native and non-native, was higher on raked plots as compared to control or hydro-slurried plots (Figure 3.7). Non-native forbs had over 2x more plants on raked sites than on control sites. For native forbs, an interaction was seen when seeding was added to raking resulting in more than 3x and 7x the number of native forb seedlings as compared to seeded only or raked only respectively. The hydro-slurry x seed and hydro-slurry alone sites resulted in 5x fewer native forbs than the raked x seeded sites. Though not significant, seeding alone resulted in 50% more seedlings compared to the hydro-seeded sites. Non-native forbs were reduced by more than one-half on hydro-slurried and hydro-seeded sites compared to the raked x seeded and raked only sites. Non-native forbs were also 35% fewer on hydro-seeded sites compared to the seeded control sites. In the hydro-seeded x raking combined factors, the number of non-native forb seedlings was suppressed by 37% compared to the raked x seeded sites.

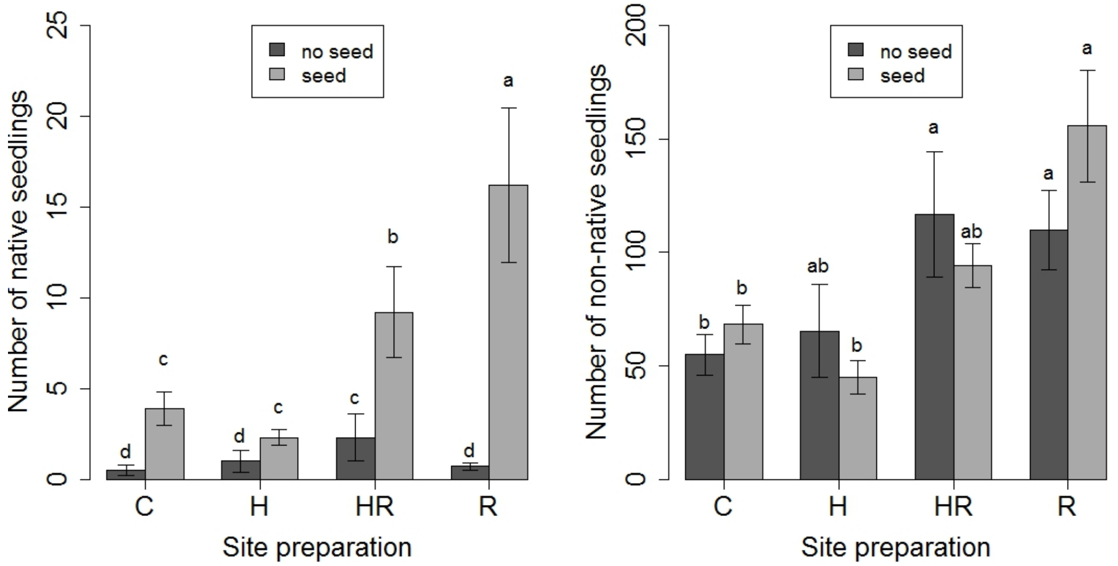

Figure 3.6: Results of seeding and soil preparation on stockpile topsoil at New Gold's New Afton Mine in the summer of 2013. Overall seedling count of native species and non-native species on plots treated with either raking (R), hydro-slurry (H), both raking and hydro-slurry (HR), control or no manipulation (C) and each of these treatments was either seeded or not seeded with native species (n=80). Treatments labelled with different letters are significantly different ($p<0.05$). Error bars represent 95% confidence interval.

The native graminoid functional group responded positively to raking x seed with 5x more seedlings than the seeded control sites (Figure 3.8). Hydro-seeding was similar to the control sites and had 6x fewer seedlings than the raked x seeded sites. Non-native graminiods were not affected significantly by any of the soil preparation treatments.

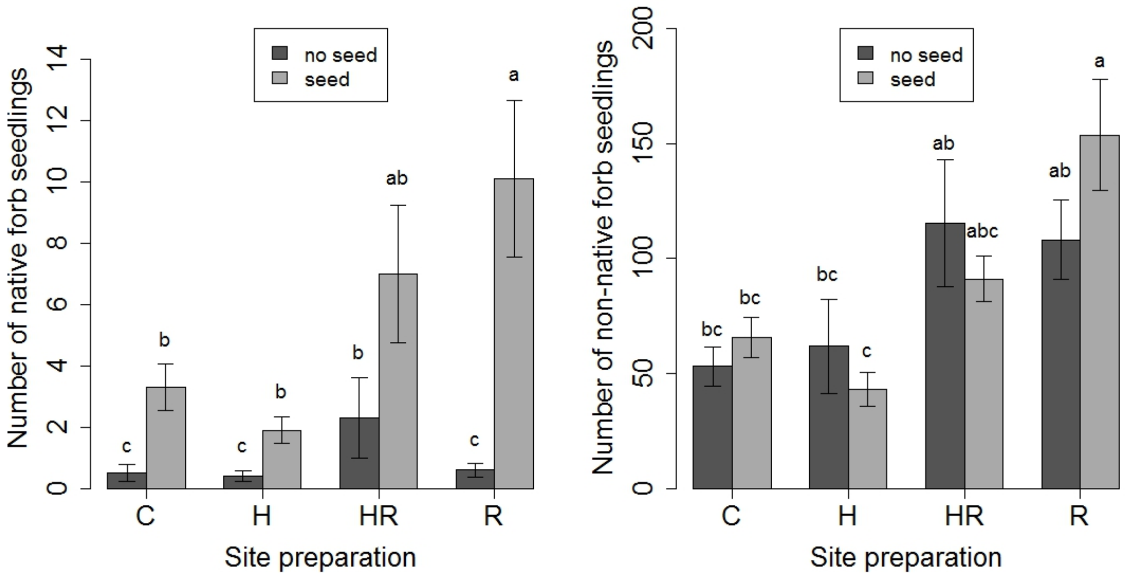

Figure 3.7: Results of seeding and soil preparation on stockpile topsoil at New Gold's New Afton Mine in the summer of 2013. Response of native forb and non-native forb species to different soil preparations on stockpiled topsoil (C = control, H = hydro-slurry, R = Raking) on stock-piled topsoil (n=80). Each level was either seeded or not seeded with native species. Note the scale for the non-native forbs is 20x greater than for the native forb species. Treatments labelled with different letters are significantly different ($p<0.05$). Error bars represent 95% confidence interval.

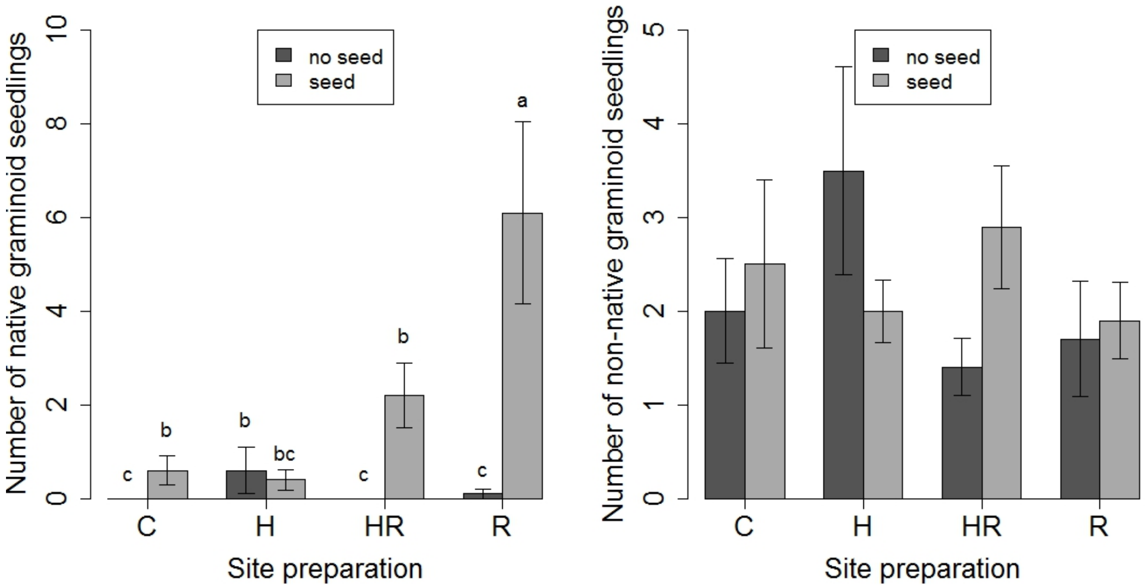

Figure 3.8: Results of seeding and soil preparation on stockpile topsoil at New Gold's New Afton Mine in the summer of 2013. Effects of soil preparation (C=control, H=hyrdo-slurry, R=raked, HR=hydro-slurry+raked) and seeding (seed /no seed) on native and non-native graminoids (n=80). Treatments labelled with different letters are significantly different ($p<0.05$). Error bars represent 95% confidence interval.

Species specific data can be found in (Appendix C).

Diversity and Richness

Species richness (*S*) was highest in the seeded treatments (Table 3.3; Figure 3.9). Seeded treatments over all site preparations resulted in *S* of approximately 10 compared to 7 on unseeded sites. The raked and raked x hydro-seeded sites had *S* of 11 and 10 respectively compared to the seeded control sites which averaged 8. The seeded control and hydroseeded only treatments were not significantly different from the unseeded control treatments. Species composition changed in the number of native species counted. On seeded sites native species increased *S* by three additional species with no displacement on the number of different non-native species (Figure 3.10).

The Shannon Diversity Index revealed a significant difference between the seeded and non-seeded treatment plots, such that seeded plots had a higher diversity at an index of 1.6

and the unseeded plots had an average index of 1.4 (Table 3.3; Figure 3.11). Site preparation as a main effect did not influence diversity; however, the interaction between seeding and site preparation was significant. Hydroseeding and hydroseeding x raking treatments had higher diversities (~1.6) than non-seeded raked treatments with an index of 1.3.

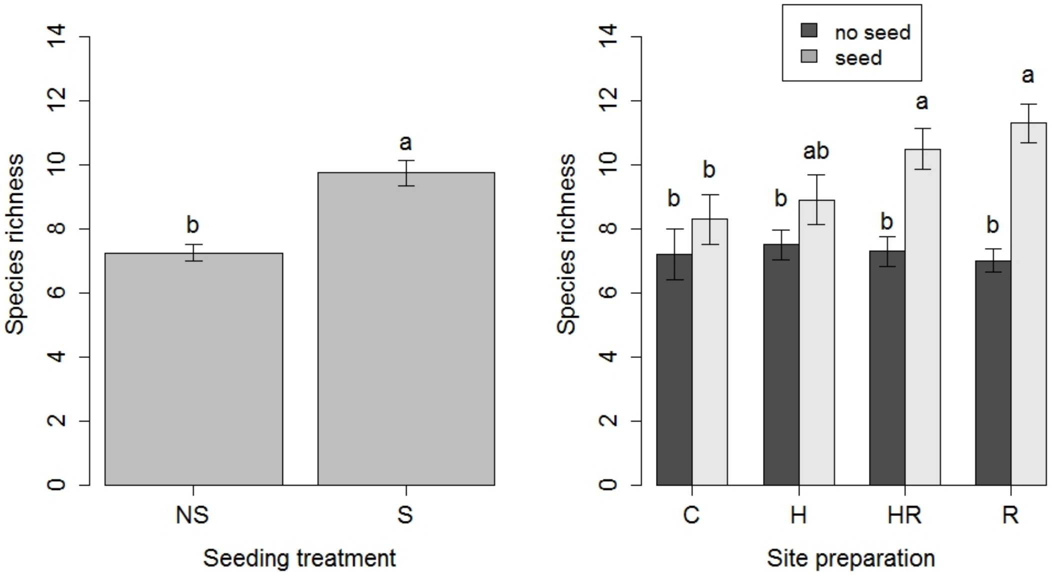

Figure 3.9: Results of seeding and soil preparation on stockpile topsoil at New Gold's New Afton Mine in the summer of 2013. Effects of soil preparation (C=control, H=hyrdo-slurry, R=raked, HR=hydro-slurry x raked) and seeding (no seed / seed) on Species Richness (n=80). Treatments labelled with different letters are significantly different (p<0.05). Error bars represent 95% confidence interval.

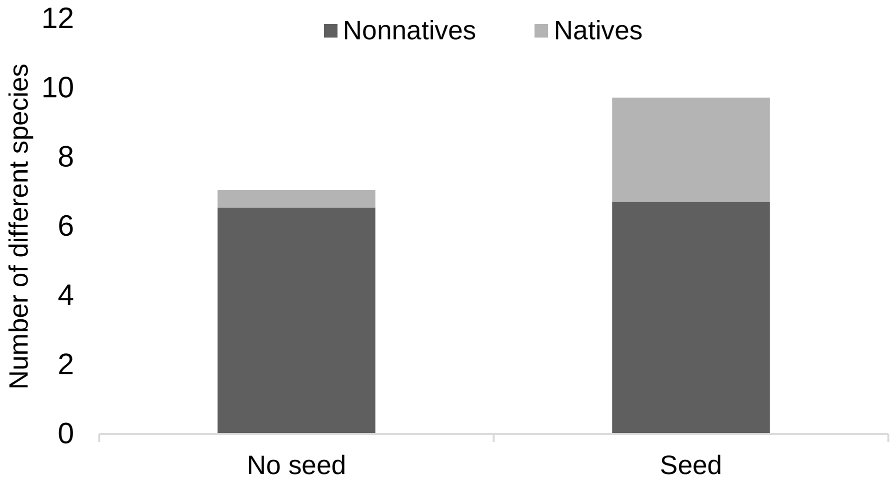

Figure 3.10: Number of different species counted on restoration study site at New Gold's New Afton Mine in the summer of 2013. Species composition consisted of mean counts over all sites (raking, hydro-slurry and control) (n=80), displayed as seeded and non-seeded sites stacked by non-native and native species.

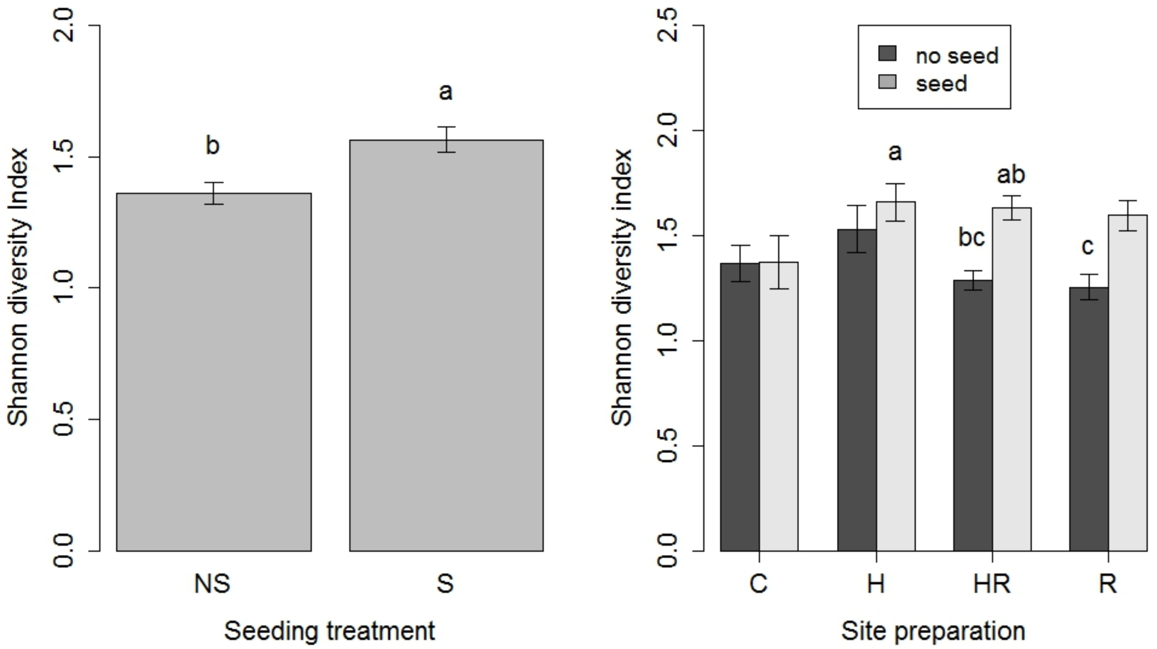

Figure 3.11: Results of seeding and soil preparation on stockpile topsoil at New Gold's New Afton Mine in the summer of 2013. Effects of soil preparation (C=control, H=hyrdo-slurry, R=raked, HR=hydro-slurry+raked) and seeding (no seed / seed) on Shannon diversity (n=80). Treatments labelled with different letters are significantly different ($p<0.05$). Error bars represent 95% confidence interval.

DISCUSSION

Successful restoration may be a product of soil preparation and seeding of desirable species. My hypothesis that raking would increase native seedling establishment was supported for native species overall and for native graminoids and forbs. The positive effect of raking was most likely due to increased seed soil contact, which is enhanced by roughing up the surface of the soil (Wilson and Gerry 1995, Montalvo et al. 2002, Kiehl et al. 2010). As well, the crevices created by raking create areas of higher moisture, humidity, wind protection and shade from the sun (Montalvo et al. 2002, Burke 2003). However, my method of raking created ridges approximately two centimeters in height at most. Even though I attempted to loosen the soil with shovels the effect of roughing and loosening the soil to enhance seeding establishment may diminish as the seedling roots reach below this loosened area into more compact soil. Certainly some of our plots were more compact than others. This was indicated by the difficulty in putting in our grid stakes as well as the difficulty we had in penetrating our shovels into the topsoil to loosen and roughen the raked sites.

The objective with the hydro-slurry was to increase establishment of native species. However, hydro-seeding had no effect on native graminoids, native forbs or even non-native forbs. As the objective of hydro-seeding was to increase germination and establishment of native species; the hydro-slurry treatment did not have the intended effect. Hydro-seeding did, however, suppress non-native forbs compared to the raked x seeded sites. Forbs overall, responded positively to the raking treatment as did the native graminoids. Contradictive to my study, Montalvo *et al.* (2002) and Tormo *et al.* (2007) found hydro-seeding to increase the germination and establishment of native species. The Montalvo study also found soil ripping of different depths had a negative impact on non-native species. In a review, Burke (2003) suggested furrow depths play a role in the germination and establishment of species. In terms of management, my study showed hydro-slurry to be ineffective as a method of restoration in the BC interior grasslands. However, further research into tilling depths may mirror Montalvo *et al.*'s (2002) study and the findings by Burke (2003) where tilling or ripping was found to suppress non-native species, while still encouraging the establishment of native species.

Unlike the native forbs, native graminoids responded positively only to the raking x seed treatment. Raking x seed resulted in a positive response from *E. trachycaulus* and *P. spicata*. Hydro-seeding native grasses had a neutral effect compared to the seeded control. The raking x seed addition treatment was the only treatment combination that resulted in an increase in seedlings. The non-native graminoids *A. cristatum* and *B. tectorum* showed no significant response to any of the treatments. Since hydro-slurry did not significantly inhibit the growth of non-native grasses and did not benefit native grasses, the hydro-slurry mixture I applied does not seem to be a feasible method of restoration of native grasses in the BC Interior.

Some non-native forb species that appear to be early successional species showed some negative response to hydro-slurry, e.g. *K. scoparia*, a Eurasian species. Mustards also appeared in the first year after disturbance. Both of these species are ephemeral and therefore, as the site ages, they ought to become less common. As succession is driven by changes within an ecosystem, the addition of organic matter from roots and above ground litter can affect both biotic and abiotic soil properties. These changes can have an impact on the pattern of colonization within disturbed ecosystems (Wali 1999). Ephemeral species that first colonize disturbed areas may play an important role in changing the soil parameters to better suit native species (Wali 1999). For example, *K. scoparia* is a halophyte and may remove salinity from disturbed soils over time (Mayland and Robins 1994, Takagi and Yamada 2013). In some ways these early successional species may also play a role in reducing wind and water erosion, as well as shade creation. However, *K. scoparia* contributes very little OM to the system due to its tumbleweed nature (Wali 1999). Wali's (1999) study looked at succession on mine sites aged 1, 7,17, 30, and 45 years. They found younger sites were dominated by non-natives like *Descuriania sophia* (year 1), *Hordeum jubatum* (years 1-7) and *Kochia scoparia* (1-17 years). They also found species richness and diversity increased with site age. Interestingly, they found that ‘weedy’ native species like *A. millefolium* did not appear on sites younger than 30 yrs. In this study *A. millefolium* was absent from sites where seed was not added. It is thus important to create a native seed mixture which can establish and compete with non-native early successional species and pave the way for further native additions to the area either by natural or manual methods.

Raking may create micro-climates on the soil surface. The loosening and roughing up of soil may form pockets thus protecting seeds from wind and water erosion that may otherwise remove them from the site. These microclimates may create areas of more or less moisture, warm and cool zones as well as increase the boundary layer between the soil and the atmosphere lowering the effects of wind and reducing the amount of evaporation from the soil surface (Burke 2003). Seed radicles may benefit from the loosening of soil creating better seed soil contact. The loosened soil may improve root penetration thus helping to anchor the young seedlings as well as allowing them better access to water, nutrients and oxygen below the soil surface. Burke (2003) showed that deep tilling, which creates furrows, increases germination and establishment success by increasing aeration, reducing compaction and helping to prevent erosion. As well, the hollows created from deep tilling may accumulate organic matter and moisture, while seeds may get caught and collect in these depressions. As such, the recommendation would be for further research to look at the effects of different depths of tilling on both the germination and establishment success of native species and exotics.

CONCLUSION

Hydro-seeding grassland species of the BC Interior was unsuccessful in terms of establishment success. As the hydro-seeding was no different than the seeded control for both native forbs and graminoids it is not recommended for restoration purposes. In contrast raking or roughening the surface before seeding has a positive effect for native species, both graminoids and forbs alike. Further research should look at the effects of tilling depths on the success of both native and non-native species.

It is also this researcher's opinion that seeding time be studied. It is possible that seeding in late summer early fall may be more appropriate for some species. In my study only half of the 24 species seeded germinated to my knowledge. It is thus possible that seeding late in the fall as I did was not conducive to good germination for those species. Some of these species may prefer fall germination allowing them to establish better root zones during the fall and in early spring when the weather warms and moisture is plentiful. However, I also suggest that those species which did germinate and establish from the late fall planting may prefer this seasonal timing for seeding. Thus, further studies should look at seasonal seeding.

This study did not test woody species, which is another area that should be studied as woody species can create shade, reduce wind effects, hold soil via their root systems reducing wind and water erosion, and their larger size can capture moisture such as blowing snow, and create habitat for fauna.

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CHAPTER 4: CONCLUSION AND MANAGEMENT SUGGESTIONS

In British Columbia the grasslands represent a small portion of the total land area (<1%), but are home to approximately 30% of BC’s species at risk at some point in their lifecycle (Iverson 2004). Protecting these fragile ecosystems is important as they play an important part in capturing, storing and filtering water, habitat for wildlife, and they hold value in terms of agriculture, recreation, education, hunting, etc. (Iverson 2004). Disturbances through the extraction of resources, development and recreation continue to increase as do demands from a growing world population. To this end it is extremely important that we learn how to mitigate disturbance and restore lands and ecosystems that have been damaged. My research was designed to help give a better understanding on how to restore disturbed semi-arid grasslands specifically in the interior of BC. We know from previous studies that propagules may be a limiting factor in natural restoration (Foster et al. 2007, Alday et al. 2011b, Cavender et al. 2014) and the addition of species results in vegetation recovery of those same species even years later (Cavender et al. 2014). Left to natural processes, restoration can take decades, hence the amelioration of soil and addition of seeds will expedite restoration (Bradshaw 1997, Baasch et al. 2012). My thesis concentrated on finding methods to help increase the success of restoration in semi-arid grasslands after a major disturbance such as mining through the use of biochar (a soil ameliorant) and site preparation (raking and hydro-seeding).

The major results of my thesis are:

- **No evidence was seen in the biochar study that it can increase the biomass of native flora of the BC interior grasslands.**

As the goal in restoration is to return a disturbed ecosystem back to a natural, self-sustaining system, finding methods to enhance the growth and establishment of native species is important. In the biochar growth experiment I found that the biochar I used did not increase above or below ground biomass of the native species studied.

- **Raking as a method of roughening and preparing the soil for seeding gives positive results in terms of germination and establishment**

Many studies have demonstrated roughening the surface before seeding can have an effect on germination and establishment of species (Montalvo et al. 2002, FLH Western Federal Lands Highway Division 2007, Dornbush and Wilsey 2010). My study also demonstrated raking or roughening the soil surface increased germination and establishment rates of native species.

- **Hydro-seeding native species did not promote increased germination and establishment**

Hydro-seeding has been used as a method to restore road embankments in the Mediterranean with some success (Tormo et al. 2007). I wanted to test whether native species from the BC interior could be used successfully in hydro-seeding disturbed areas. My study demonstrated hydro-seeding was not significantly different from broadcast seeding alone.

MANAGEMENT RECOMMENDATIONS

The soil amendment biochar has recently come to the forefront as a method to restore soil by managing toxins and heavy metals within the soil (Beesley and Marmiroli 2011, Park et al. 2011), increasing the activity of soil micro-organisms (Lehmann et al. 2011, Quilliam et al. 2012), reducing compaction while increasing porosity (Revell et al. 2012), reducing leaching of nutrients (Lehmann and Joseph 2010) and increasing plant biomass (Vaccari et al. 2011, Uzoma et al. 2011, Schulz et al. 2013). My growth experiment demonstrated that biochar did not increase the overall above or below ground biomass of native species. Biochar may still hold potential for the use in restoration in the semi-arid grasslands of BC. As ecological processes take time, it is of the researcher’s opinion that further research should be undertaken in the field to better simulate the natural conditions that will affect the restoration process at the time of mine closure. The next phase should be to study biochar in field experiments over longer periods (1-10 yrs) to see the effects on growth above and below ground. Researching the addition of biochar to stockpiled topsoil will increase our knowledge in the use of biochar as a soil amendment in restoration practices within disturbed grassland ecosystems. Included in these studies should be chemical soil parameters such as pH, nutrient retention, soil building, soil density and moisture holding capacity, microbial status, and plant growth above and below ground. The reproductive ability of plants in soil with biochar should also be looked at to ensure optimum seed output and viability are maintained or enhanced. As different types of biochar can have varying effects on soil parameters (Alburquerque et al. 2014) it will also be important to study biochars from different feedstocks.

My thesis also looked at methods of seeding and soil preparation in the field. I confirmed that seeding native species resulted in more native seedlings being found on site, as well as increasing species richness and diversity. As the end goal to restoration is to return an ecosystem back to its natural self-sustainable processes (Alday et al. 2011a), the seeding of native species is required. I found methods of seeding and different soil preparations had an effect on the success of seedling establishment. I also found that hydro-seeding, as a method of sowing seed, decreased the number of native seedlings counted, while at the same time suppressing non-native species. Hydro-seeding is touted as a method to control erosion while increasing germination and establishment (Alday et al. 2011b). However, I found hydro-seeding had similar results to my control plots and therefore had little impact on the germination and establishment of semi-arid grassland species. For this reason I do not recommend hydro-seeding in the restoration of disturbed areas in the BC interior grasslands. A more appropriate method may be the use of native hay, which could provide both litter and seeds. Another approach would be to plant successionally. Those species which germinate and establish first in disturbed areas should be used in the first planting. After a few years additional native species, which require either litter or altered soil chemistry to successfully germinate, should be seeded into the area. Further research to determine an appropriate successional seeding and planting plan should be undertaken.

Wind erosion is a problem due to the dry climate in the BC interior. Further research should be carried out to look at alternative methods to mitigate the effects of wind erosion. One method may be to use snow fences strategically placed to reduce wind erosion, increase snow capture in the winter and play a role in catching soil, litter and seeds (Carrick and

Krüger 2007). Catchments can create dense vegetative areas and these areas have the potential to increase seed rain thus expediting the restoration process. Using native grassland hay which contains both seeds and litter may also help expedite the restoration process (Baasch et al. 2012). The use of litter may reduce erosion while adding nutrients and protection for seed germination and seedling establishment. Another benefit of litter may be shade, which reduces evaporation and helps to retain soil moisture. Unlike the hydro-slurry where seeds may be caught in the slurry and unable to make contact with the soil, the litter may allow for seeds to fall through giving them access to soil moisture and nutrients while being protected from the harsher climate above.

Another way to reduce evaporation and transpiration without the use of litter, may be shade netting. Shade netting may provide some protection from the sun during the heat of the summer months. If cooler temperatures and reduced evaporation can be accomplished it may increase the germination and establishment rates of new seedlings.

Raking, as a method of soil preparation, increased the success of native species sown. However, as the raking was done by hand it did not penetrate the soil more than a few centimetres. Yet even with that small amount of surface roughening I found a significant increase in the number of native species counted on sites. It is recommended that raking should be done before seeds are sown. Tilling has been shown by others to increase native species success (Wilson and Gerry 1995, Turner et al. 2006). Further investigation should be carried out with respect to landscape manipulation and various tilling depths. In areas that are compact, it is important to alleviate the compaction and increase porosity in the root zone. This will allow for improved water and root infiltration (FLH Western Federal Lands Highway Division 2007). Landscaping of mounds and hollows will create slopes and aspects, which may result in better germination and establishment of some species, while also having an effect on wind and water movement. The creation of natural microsites through the use of rocks, tree wood, and fashioning of humps and hollows may result in increased germination of specific species. This form of creating heterogeneity on the landscape should be studied. The addition of woody species such as *Amelanchier alnifolia* (Saskatoon), *Shepherdia canadensis* (soapberry – a nitrogen fixer), *Ericameria nauseosa* (rabbitbrush) and *Artemisia tridentata* (big sagebrush) should also be studied as to their effect on erosion and establishment of non-woody species.

Some species sowed did not germinate within any of the treatment sites. Restoration success for these species may depend on different methods of re-introduction (Montalvo et al. 2002). Some species may need to be introduced into the system after a number of years. This may be because the soil parameters, plant heterogeneity, and lack of litter in disturbed areas are not suitable for these species in the preliminary stages of restoration. Over time the addition of plant litter from a varied plant community and the altered biotic and abiotic soil factors may result in a more suitable environment for these species (Wali 1999, Burke 2003, Grman et al. 2013). As well, studies have shown that using local native seed may increase the success of restoration (Foster et al. 2007, Kirmer et al. 2012). Other than the seeds we collected by hand in the local grasslands close to our study site, all others were obtained through a company from various production locations.

Competition for space and nutrients can be an issue. It’s possible that introducing later successional species via seedling plugs rather than seed may increase their success rate. Forestry uses plugs to successfully revegetate deforested areas (Kostopoulou et al. 2010), hence it’s plausible that similar methods can be used to restore grasslands. As there was a hint in our growth study that the addition of biochar may increase transplanting success, research should be carried out on the re-introduction of grassland seedlings and the effect biochar may have on establishment success.

Successional planting may be an important aspect of restoration. The first step of which should be identifying the species to be seeded first which will help set the groundwork for later plantings or natural succession. Concentrating on native species that will colonize quickly thus reducing erosion and adding litter to the area is an important aspect to the early successional level of restoration (Egawa and Tsuyuzaki 2013). Further, some species have the ability to colonize disturbed areas with little assistance. Alday *et al.* (2011b) found that over time species which had the ability to disburse long distances found their way into study sites from neighbouring natural sites. However, species which do not have the ability to disburse long distances will need assistance moving into restored communities and possibly at later stages of succession. Successful restoration of disturbed areas then, depends on designing and implementing site specific strategies.

CONCLUSIONS

My results contribute to the knowledge needed for the restoration of disturbed semi-arid grasslands in the BC interior. These findings can also be applied to the restoration of semi-arid grasslands in other regions around the globe. As semi-arid ecosystems are water limited resulting in soils that are slow to build and soil disturbance and access to native propagules may be poor, research into different methods of restoration is extremely important. To date, no other studies to my knowledge, have looked at biochar as a method of soil amelioration in the semi-arid grasslands of BC. This research can be used as a starting point for further research into the use of biochar as a method of restoring semi-arid plant communities.

In my field study I demonstrated that soil preparation is an important aspect of successful establishment of native semi-arid grassland species. Of the 24 species planted, only half of them germinated and established. However, the species that did appear may be species that can be exploited in terms of creating a seeding mixture for restoration. Seeding these species may help in restoring the natural soil parameters and prepare the way for seeding or planting of other indigenous species.

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APPENDIX A: Biochar germination study

Biochar has been shown to increase germination rates (Oh et al. 2012, Revell et al. 2012). I therefore expect the addition of biochar to increase seed germination. I also expect larger seeded species to have higher germination success than smaller seeded species as larger seeds hold the potential for more stored energy (Moles and Westoby 2006, Volis and Bohrer 2012).

Hypotheses

1) Biochar ratios will positively influence the germination of native forb and graminoids species in the greenhouse.
2) Topsoil will have a positive effect on the germination success of native forb and graminoids species compared to sand or sand+topsoil.
3) Larger seeded species will have greater germination success due to their increased energy stores compared to smaller seeded species.

METHODS

The average dry weight of the 60 mL samples was determined for each of the soil mediums and the biochar. This information was used to determine the percent volume by weight to be used in the study. The biochar was soaked in tap water for two weeks and stirred daily to ensure all particles came in contact with and absorbed water before being mixed with soil medium treatments. The soil mixtures were prepared in 2L batches with the appropriate amount of biochar being added. Mixtures of 0%, 1%, 5% and 10% biochar volume by weight were prepared.

Once seeded, the petri dishes were placed in the Greenhouse in a randomized block layout. A tent was created over the table using heavy plastic sheets to help control air temperature and humidity. An air-conditioner attached to the outside wall of the greenhouse was sealed in the tent in order to maintain a temperature between 15°C (night) and 22°C (day). All dishes were watered to the point of saturation. During the study period soil mediums within petri dishes were checked daily and kept damp using a manual hand pump sprayer. Germination counts were taken each day after the first seeds began to germinate. As seeds germinated they were counted, recorded and then removed from the dishes each day over a 30 day period.

Statistical Analysis

Data for the germination experiment were analyzed using R Studio version 2.15.3 (2013). The analysis by species for the biochar on germination was not normally distributed for six species and one species did not show homogeneity of variances. These species data were arcsine transformed before carrying out an ANOVA followed by a Tukey-HSD posthoc test.

Seeds were grouped by size to determine if size was a factor in germination success. Seeds weighing less than 1 mg were group #1, those between 1 and 2 mg were group #2 and the remaining species, weighing between 3 mg and 4.7 mg were group #3. The data for seeds grouped by weight followed a normal distribution and showed homogeneity of variances. The seed size data were statistically analyzed using ANOVA followed by a Tukey-HSD posthoc test. All data were tested for significance at $p \leq 0.05$.

RESULTS

Soil medium affected species germination, but there was no effect of the biochar treatments or interaction effects by biochar and soil medium (Table A.1). Separating species by seed size into three groups (group 1: <1 mg, group 2: >1<2 mg; and group 3: >2 mg,) resulted in an effect of seed size (A.1), but no effect was seen with soil medium or biochar within the seed size groupings. The largest seeds (group 3) had the highest average germination over all soil mediums (sand, topsoil, and sand+topsoil) at 74%, and group 2 seeds had the lowest germination rate at 47%.

The germination success of seeds exposed to sand was higher than those of the three soil mediums studied. Seeds exposed to sand had a 68% germination rate overall, while seeds exposed to topsoil alone had a 60% germination rate (A.2). At the species level, two grass species, *Festuca campestris* and *Pseudoroegneria spicata* and two forb species, *Gaillardia aristata* and *Geum triflorum* responded to the different soil mediums (Table A.1). *F. campestris* showed a negative response to topsoil while sand resulted in higher germination rates (A.3). A germination rate of ~81% was seen with the sand medium while topsoil averaged ~60%. The 50/50 mixture of topsoil and sand for *F. campestris* was also significantly less than sand alone with a germination rate just slightly higher than 60%. A difference was also found between the control sand treatment and the topsoil treatment for *P. spicata* (A.4). A germination rate of 88% was exhibited on sand while topsoil resulted in a 16% decrease in germination at 72%. However, the 50/50 mixture of sand and topsoil was not significantly different from either the sand control treatment or the topsoil treatment.

Table A.1: Results from 2-way ANOVAs for germination experiment consisting of soil medium (sand, topsoil and sand+topsoil) and biochar rate (0%, 1%, 5% and 10%) on germination percentage of native species from the BC interior grasslands (n=480). Confidence level was set at 0.95 ($p \leq 0.05$).

	Germination Experiment (2-way ANOVA)			
	Soil Medium		**Biochar Rate**	
Species	**F-value**	**P-value**	**F-value**	**P-value**
All species	**3.306**	**0.038**	0.177	0.912
Graminoids	1.645	0.195	0.147	0.932
Forbs	2.406	0.093	0.077	0.973
Achillea millefolium	2.085	0.139	1.160	0.338
Elymus glaucus	2.955	0.065	1.318	0.284
Elymus trachycaulus	0.100	0.905	0.787	0.509
Erigeron corymbosus	0.647	0.529	0.010	0.999
Festuca campestris	6.928	**0.003**	0.044	0.988
Gaillardia aristata	4.322	**0.021**	3.688	**0.021**
Geum triflorum	4.128	**0.024**	1.262	0.302
Hesperostipa comata	0.869	0.428	1.290	0.293
Oxytropis campestris	1.154	0.327	0.332	0.802
Pseudoroegnaria spicatum	**3.787**	**0.032**	0.250	0.861
Seed Size (All)	**4.497**	**0.012**	0.204	0.894
< 1mg	1.011	0.368	0.289	0.833
< 2mg	2.154	0.120	0.119	0.949
> 3mg	1.491	0.227	0.845	0.470

* Trend

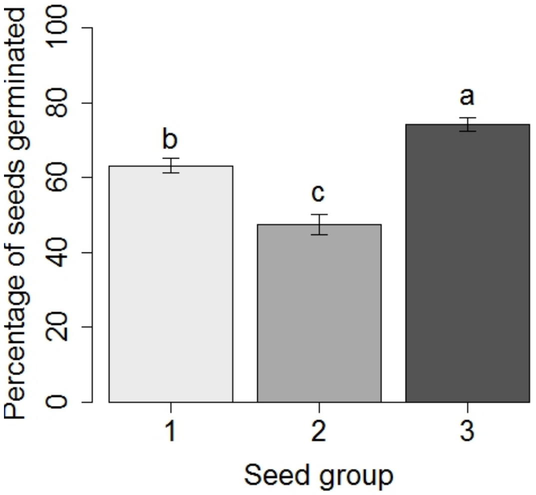

Figure A.1: Effects of seed size as determined by three seed weight categories: <1mg, >1<2mg and >3mg, on the percentage of seeds germinated on all three soil mediums investigated (sand, topsoil and sand+topsoil). 10 native arid grassland species from the Lac du Bois grasslands in British Columbia were studied over a 26 day period (n=480). Treatments labelled with different letters are significantly different ($p<0.05$). Error bars represent 95% confidence interval.

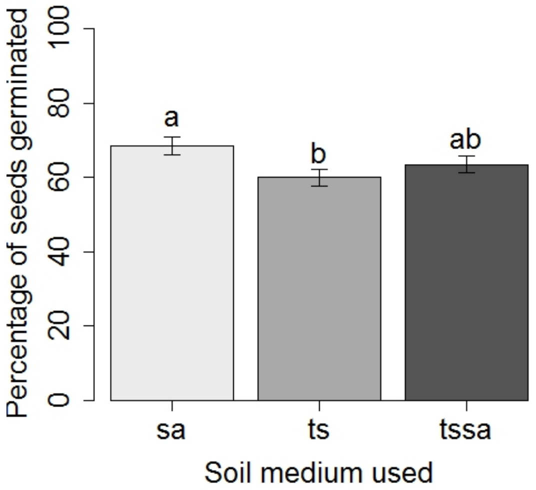

Figure A.2: Effects of soil medium on the percent germination of 10 native grassland species (n=480). Soil mediums represented are sand (sa), topsoil (ts) and topsoil+sand (tssa). Topsoil was obtained from stockpiled topsoil at New Gold's New Afton Mine site. Treatments labelled with different letters are significantly different ($p<0.05$). Error bars represent 95% confidence interval.

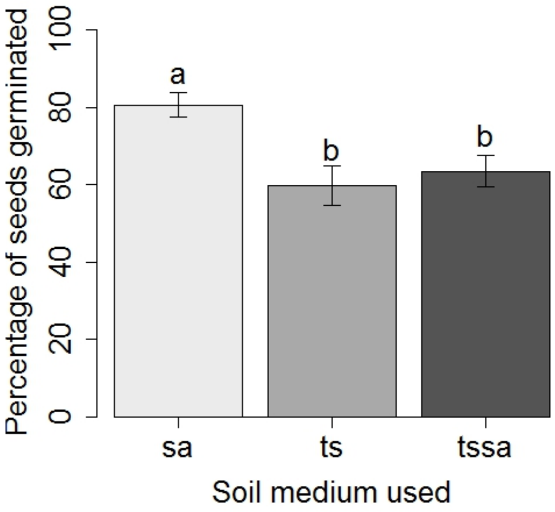

Figure A.3: Effects of soil medium (sa=sand, ts=topsoil, tssa=topsoil+sand) on the percent germination of *Festuca campestris* (n=48) over a 26 day period. Topsoil was collected from New Gold's New Afton Mine Site. Treatments labelled with different letters are significantly different (p<0.05). Error bars represent 95% confidence interval.

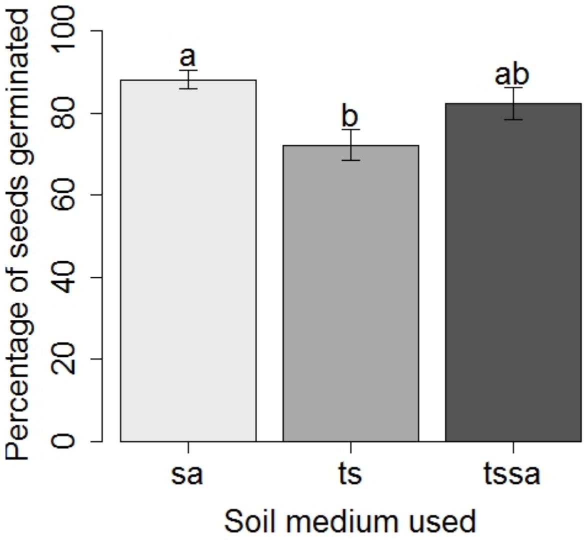

Figure A.4: Effects of soil medium (sa=sand, ts=topsoil, tssa=topsoil+sand) on the percent germination of *Pseudoroegnaria spicata* (n=48) over a 26 day period. Topsoil was collected from New Gold's New Afton Mine Site. Treatments labelled with different letters are significantly different (p<0.05). Error bars represent 95% confidence interval.

Of the five forbs seeded, only *Gaillardia aristata* and *Geum triflorum* showed any significance. However, unlike the graminoids, differences in germination rates were found within treatments for biochar as well as soil medium. For *G. aristata*, the control (0%) biochar rate showed significantly higher germination rates at 88% vs 65% from the 5% biochar rate (A.5). As with the graminoids, the soil medium (sand) showed significantly higher germination rates then the topsoil at 74% and 57% respectively (A.6). The topsoil+sand mixture was not significantly different from the other two treatments having a germination rate of 65%. *Geum triflorum* had no significant differences between biochar rates, but did have differences in the soil medium treatments. The germination rates were again significantly higher in the sand medium vs the topsoil medium. The sand treatment had an average germination rate of 74% while the topsoil treatment averaged 57% (A.7).

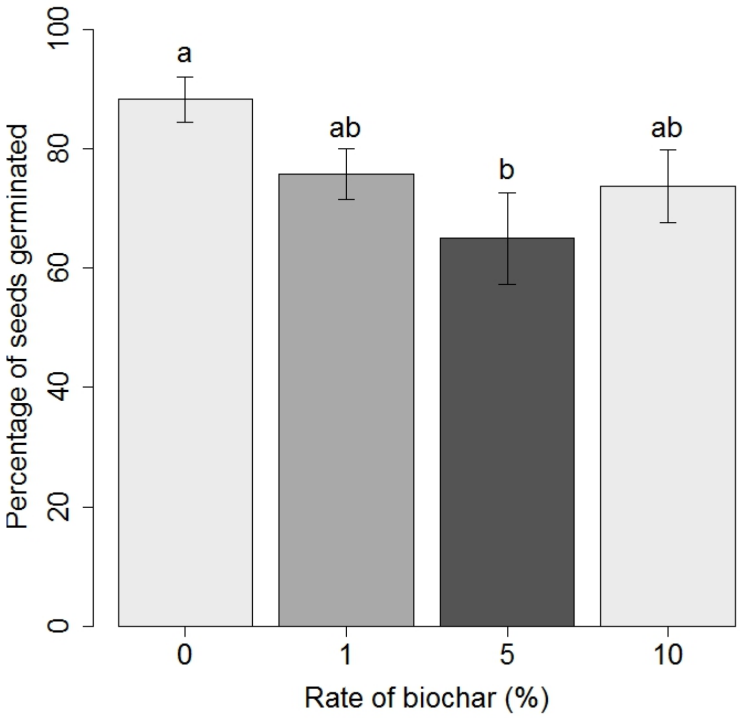

Figure A.5: Effects of biochar rate (volume by weight) mixed with topsoil, from New Gold's New Afton Mine Site, on the percent germination of *Gaillardia aristata* (n=48) over a 26 day period. Treatments labelled with different letters are significantly different ($p<0.05$). Error bars represent 95% confidence interval.

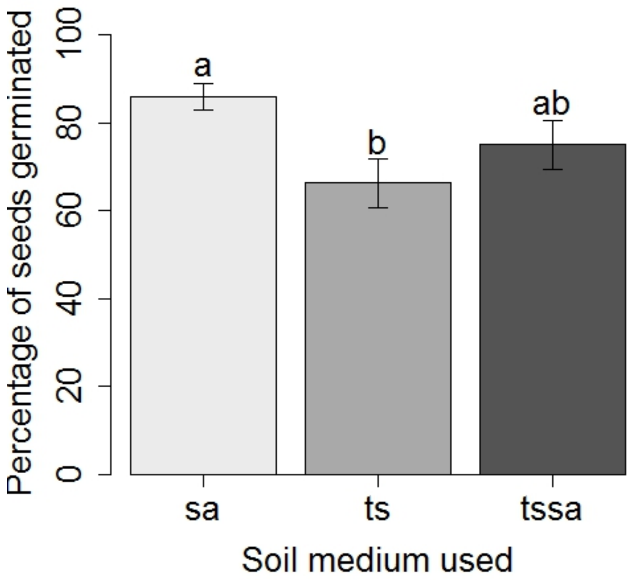

Figure A.6: Effects of soil medium (sa=sand, ts=topsoil, tssa=topsoil+sand) on the percent germination of *Gaillardia aristata* (n=48) over a 26 day period. Topsoil was collected from New Gold's, New Afton Mine Site. Treatments labelled with different letters are significantly different ($p<0.05$). Error bars represent 95% confidence interval.

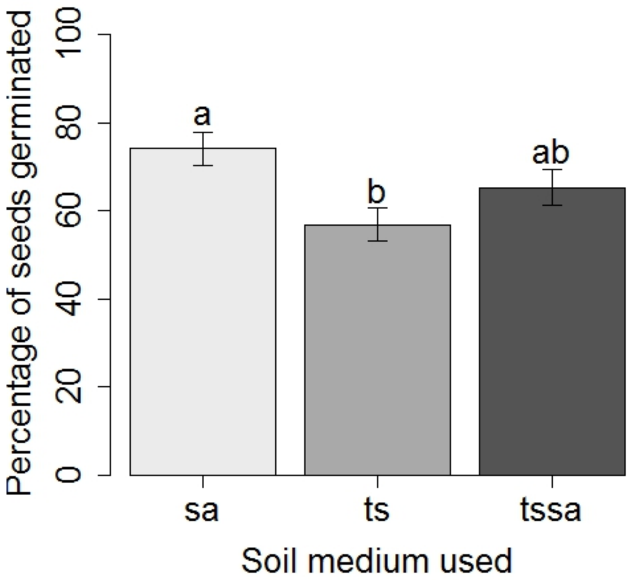

Figure A.7: Effects of soil medium (sa=sand, ts=topsoil, tssa=topsoil+sand) on the percent germination of *Geum triflorum* (n=48) over a 26 day period. Topsoil was collected from New Gold's New, Afton Mine Site. Treatments labelled with different letters are significantly different ($p<0.05$). Error bars represent 95% confidence interval.

DISCUSSION

There was little evidence to support the hypothesis of increased seed germination with the addition of biochar. *Gaillardia aristata* appeared to be the only species influenced by the rate of biochar used with a significant decrease in germination rate from the 0% biochar treatment to the 5% treatment. It is possible the biochar altered the pH or interfered with chemical aspects of the soil needed for successful seed germination. However, the biochar rate of 10% increased the germination rate resulting in no difference between 0%, 1% and 10%.

When looking across all the species studied, significance was found between topsoil and the sand treatments for four of the 10 species. As the topsoil treatments resulted in lower seed germination rates, it is plausible that there was biological or chemical inhibition occurring. It may be that the topsoil is responsible for the reduced seed germination rate as it could contain pathogens which inhibit germination (Brown and Venable 1988). As the stockpiling of topsoil can change the chemical and biological aspects of the soil, having pre-disturbance knowledge of biological and chemical aspects of the soil would be beneficial. An understanding of the native organisms within undisturbed reference cites and the role they play in the success of a grassland community would potentially aid in restoration. For example, the belowground community of macro and micro-organisms which play a role in breaking down parent material such as litter into useable forms of nutrients (Wardle et al. 2004) may play a role in restoration success through chemical changes to the soil as a result of their presence. Soil organisms may also have an effect on succession. Deyn *et al.* (2003) found the addition and removal of soil organisms on primary, secondary and late successional plant communities altered the communities and contributed to how successional processes developed in terms of plant community structure. As such, disturbance of microbial communities may also have detrimental effects on seed germination, seedling establishment and therefore succession, as pathogens and other microbial species may be adversely affected thus shifting the plant community structure (Thrall et al. 1997). Therefore finding amendments which may enhance the rebuilding of the belowground biological community within a disturbed area may be the key to more successful restoration efforts.

Seed size affected germination rates. All three groups differed significantly from each other with the largest seeds having the highest germination rate and the smallest seeds having the second highest germination rate. Seed size is an evolutionary trait and has been connected with germination rate and success (Eriksson and Kainulainen 2011). For the larger seeds, it may be that the stored energy within the seed allows for a higher germination rate (Brown and Venable 1988). However, it is unclear why the medium sized seeds in our study had lower germination rates than both the large seed group and the small seed group.

Smaller seeded species may have evolved to take advantage of early germination thus avoiding competition for resources in the early stages of growth (Zhang et al. 2014). In a study by Zhang *et al.* (2014) germination rate was found to be related to seed mass. The study used different light conditions (high light to low light) to simulate sun and shade conditions. They found smaller seeded species germinated before larger seeded species at all light conditions. As small seeded species do not have the level of carbon reserves as larger seeded species (Eriksson and Kainulainen 2011), there is an advantage to germinating early and accessing nutrients, light and water while avoiding competition for resources. Early germination could thus, potentially give smaller seeded species an advantage over the medium sized seed group. However, this does not explain the better germination success of the smaller seeded species in our study.

Achillea millefolim, from the smallest seeded group, is a fast-growing, competitive species (Bostock and Benton 1979), and its presence may have altered the outcome of the small-seeded group giving it a higher germination rate and skewing the results. According to Bostock (1978), *A.millefolium* is able to remain viable through varying temperatures, light regimes and storage periods. He also found *A. millefolium* to be more efficient at water uptake in comparison to other grassland species. These attributes lend to *A. millefolium's* opportunistic and competitive nature. Adding more species to this group size may alter overall germination percentage within the group, potentially giving a more accurate depiction of germination success in small seeds. As this study was a greenhouse study, further research should be carried out in the field to help determine the best methods of restoration for a semi-arid grassland community.

- **Biochar did not inhibit germination of native species to the BC interior grasslands**

As biochar has been shown in other studies to have a positive effect on many aspects of restoration (soil rehabilitation, nutrients and plant growth), I wanted to test whether the same result would be found on stockpiled topsoil from a mine within the interior grasslands of BC. My germination study showed that biochar did not have a negative impact, but also did not increase germination rates in the greenhouse.

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APPENDIX B: Fertilizer used in the growth experiment from Plant Prod. All purpose fertilizer 20-20-20 included both macro and micro nutrients.

Fertilizer: 30 grams to 10 litres of water = 3g/L
Nitrogen (20%): 0.6g
Available phosphorus acid (20%): 0.6g
Soluble potash (K2O)(20%): 0.6g
Boron (0.02%): 0.0006g
Chelated copper (0.05%): 0.0015g
Chelated iron (Fe) (0.10%): 0.003g
Chelated Mn (0.05%): 0.0015g
Chelated Zn (0.05%): 0.0015g

APPENDIX C: Species specific field data including those of cultural significance

At the species level, there were effects of site preparation and seeding on the number of individuals (Table C.1). With respect to native forbs, there was a greater number of *Achillea millefolium* plants in sites that were raked x seeded or undisturbed x seeded compared with the hydro-seeded sites. On average three seedlings were found on raked and seeded sites and no seedlings were found on hydroseeded sites. The control seeded sites also had significantly more seedlings than the hydroseeded site at half the number of seedlings as the raked x seeded sites (Figure C.1). *Balsamorhiza sagittata* had greater numbers on sites that had been raked x hydro-seeded at an average of three seedlings on these sites. On the hydro-seeded only and raked only sites, *B. sagittata* averaged less than one seedling. *Gaillardia. aristata* had the greatest number of individuals on sites that had either been raked (~5 seedlings) or hydro-seeded x raked (~4 seedlings). Hydro-seeded sites alone had significantly less seedlings of *G. aristata* averaging one seedling. Many non-native forbs showed very little preference to soil preparation treatments. *Salsa tragus* (an invasive exotic) was one of the exceptions and had greater numbers of individuals in the raked plots at an average of 54 plants. Hydro-slurry resulted in significantly fewer plants than raked sites at an average of 18.2 (Figure C.1). Two graminoid species, *Elymus trachycaulus* and *Pseudoroegneria spicata* exhibited a positive response to raking x seed with an average of two and three seedlings repectively. Hydro-seeding alone resulted in no seedlings for either *E. trachycaulus* or *P. spicata* (Figure C.2). Non-native graminoids, *Agropyron cristatum* and *Bromus tectorum*, showed no significant differences between different soil treatments.

Other non-native species responded to both the seeding treatments and the soil preparation treatments (Table C.1). *Kochia scoparia* responded positively towards raking and negatively towards the hydro-slurry. The hydro-slurry reduced the number of plants by approximately 85% on the seeded sites and 75% on the non-seeded sites. *Sisymbrium loeselii* also responded positively to raking, but was suppressed by the hydro-slurry. For the sites that were hydro-seeded, *S. loeselii* was suppressed by approximately 83% and the hydro-slurry with no seed reduced *S. loeselii* by 41%.

Table C.1: Results from 3-way ANOVAs, raking (raking/no raking), hydro-slurry (hydro-slurry/no hydro-slurry) and seeding (Seed/No Seed) on numbers of native and non-native species on stockpiled topsoil at New Gold's New Afton Mine Site (n=80). Results were also compiled for Shannon diversity and species richness. Columns labelled RxH, RxS, HxS and RxHxS represent interactions between raking (R), hydro-slurry (H), and seed (S). Confidence level was set at 0.95 (p≤0.05).

	Rake	**Hydro-slurry**	**Seed**	**RxH**	**RxS**	**HxS**	**RxHxS**
	F(P-value)	**F(P-value)**	**F(P-value)**	**F(P-value)**	**F(P-value)**	**F(P-value)**	**F(P-value)**
Native forbs (seeded)							
Achillea millefolium	**4.01 (0.05)**	**24.98 (3.92e-06)**	**41.31 (1.24e-08)**	0.33 (0.57)	**4.01 (0.05)**	**24.98 (3.92e-06)**	0.33 (0.57)
Balsamorhiza sagittata	**7.50 (0.01)**	**7.50 (0.01)**	**20.76 (2.07e-05)**	3.31 (0.07)*	**7.46 (0.01)**	**7.46 (0.01)**	3.31 (0.07)*
Erigeron filifolius	0.04 (0.85)	**4.16 (0.05)**	1.24 (0.27)	0.04 (0.85)	1.24 (0.27)	1.24 (0.27)	1.24 (0.27)
Fritillaria pudica	0.00 (1.00)	2.00 (0.162)	2.00 (0.162)	0.00 (1.00)	0.00 (1.00)	2.00 (0.162)	0.00 (1.00)
Gaillardia aristata	**12.79 (0.00)**	0.11 (0.74)	**28.74 (9.54e-07)**	0.03 (0.84)	**3.92 (0.05)**	2.54 (0.12)	1.96 (0.17)
Mentzelia laevicaulis	1.25 (0.27)	0.38 (0.54)	**4.48 (0.04)**	0.38 (0.54)	1.25 (0.27)	0.38 (0.54)	0.38 (0.54)
Native forbs (volunteer)							
Artemisia tridentate	3.24 (0.08)	0.36 (0.55)	3.24 (0.08)*	0.36 (0.55)	3.24 (0.08)*	0.36 (0.55)	0.36 (0.55)
Artemisia frigidata	0.45 (0.51)	**4.03 (0.05)**	0.90 (0.35)	2.61 (0.11)	0.00 (1.00)	0.00 (1.00)	0.90 (0.35)
Astragalus tenellus	0.33 (0.57)	0.33 (0.57)	0.33 (0.57)	0.33 (0.57)	0.33 (0.57)	0.33 (0.57)	3.00 (0.09)*
Non-native forbs							
Berteroa incana	0.00 (1.00)	0.00 (1.00)	2.00 (0.16)	2.00 (0.16)	0.00 (1.00)	2.00 (0.16)	0.00 (1.00)
Camelina microcarpa	0 (1.00)	1.00 (0.32)	1.00 (0.32)	1.00 (0.32)	1.00 (0.32)	0 (1.00)	1 (1.00)
Centaurea stoebe	1 (1.00)	2 (1.00)	3 (1.00)	2.00 (0.16)	2.00 (0.16)	2.00 (0.16)	2 (1.00)
Chenopodium album	0.05 (0.82)	2.16 (0.15)	0.09 (0.76)	0.00 (1.00)	1.05 (0.31)	1.72 (0.19)	0.41 (0.53)
Descurainia sophia	0.00 (1.00)	0.00 (1.00)	**4.00 (0.05)**	0.00 (1.00)	0.00 (1.00)	0.00 (1.00)	0.00 (1.00)
Kochia scoparia	**37.87 (3.85e-08)**	**5.17 (0.03)**	0.09 (0.76)	0.00 (0.98)	0.00 (0.99)	3.37 (0.07)	1.41 (0.24)
Lactuca serriola	1.00 (0.32)	1.00 (0.32)	1.00 (0.32)	1.00 (0.32)	1.00 (0.32)	1.00 (0.32)	1.00 (0.32)
Lepidium densiflorum	3.00 (0.09)*	0.33 (0.57)	0.33 (0.57)	0.33 (0.57)	0.33 (0.57)	0.33 (0.57)	0.33 (0.57)
Medicago lupulina	1.70 (0.20)	1.12 (0.29)	0.14 (0.71)	0.51 (0.48)	2.73 (0.10)	0.51 (0.48)	1.12 (0.29)
Melilotus alba	3.02 (0.08)*	**4.99 (0.03)**	1.87 (0.18)	2.68 (0.11)	0.41 (0.53)	0.00 (0.96)	0.13 (0.72)
Myosotis sp.	0.33 (0.57)	3.00 (0.09)*	0.33 (0.57)	0.33 (0.57)	0.33 (0.57)	0.33 (0.57)	0.33 (0.57)
Polygonum aviculare L	0.48 (0.49)	0.03 (0.86)	0.03 (0.88)	2.20 (0.14)	1.85 (0.18)	0.00 (1.00)	1.45 (0.23)
Rumex acetosella	1.00 (0.32)	1.00 (0.32)	1.00 (0.32)	1.00 (0.32)	1.00 (0.32)	1.00 (0.32)	1.00 (0.32)

	Rake **F(P-value)**	**Hydro-slurry** **F(P-value)**	**Seed** **F(P-value)**	**RxH** **F(P-value)**	**RxS** **F(P-value)**	**HxS** **F(P-value)**	**RxHxS** **F(P-value)**
Salsola tragus	**11.16 (0.00)**	1.31 (0.26)	0.10 (0.76)	0.11 (0.75)	0.10 (0.76)	1.73 (0.19)	0.08 (0.78)
Sisymbrium loeselii	**20.90 (1.96e-05)**	3.66 (0.06)*	0.11 (0.74)	1.44 (0.23)	2.95 (0.09)	2.45 (0.12)	0.02 (0.90)
Taraxacum officinale	2.00 (0.16)	0.00 (1.00)	0.00 (1.00)	0.00 (1.00)	0.00 (1.00)	2.00 (0.16)	2.00 (0.16)
Thlaspi arvense	1.00 (0.32)	1.00 (0.32)	1.00 (0.32)	1.00 (0.32)	1.00 (0.32)	1.00 (0.32)	1.00 (0.32)
Native grasses							
Elymus glaucus	0.27 (0.60)	1.58 (0.21)	**5.29 (0.02)**	0.27 (0.60)	0.27 (0.60)	1.58 (0.21)	0.27 (0.60)
Elymus trachycaulus	3.58 (0.06)*	1.84 (0.18)	3.58 (0.06)*	**6.53 (0.01)**	**9.55 (0.00)**	**6.53 (0.01)**	1.84 (0.18)
Festuca sp	2.94 (0.10)	0.01 (0.94)	**14.48 (0.00)**	0.46 (0.50)	2.93 (0.09)*	0.01 (0.94)	0.46 (0.50)
Poa sandbergii	1.00 (0.32)	1.00 (0.32)	1.00 (0.32)	1.00 (0.32)	1.00 (0.32)	1.00 (0.32)	1.00 (0.32)
Pseudoroegneria spicata	**27.82 (1.34e-06)**	**5.88 (0.02)**	**23.14 (8.02e-06)**	**5.88 (0.02)**	**23.14 (8.02e-06)**	**3.85 (0.05)**	**3.85 (0.05)**
Sporobolus cryptandrus	2.25 (0.138)	2.25 (0.138)	2.25 (0.138)	2.25 (0.138)	2.25 (0.138)	2.25 (0.138)	2.25 (0.138)
Non-native grasses							
Agropyron cristatum	0.70 (0.41)	0.79 (0.38)	1.50 (0.22)	0.89 (0.35)	2.44 (0.12)	0.00 (0.96)	**5.50 (0.02)**
Bromus squarrosus	0.00 (1.00)	0.00 (1.00)	2.00 (0.16)	2.00 (0.16)	0.00 (1.00)	0.00 (1.00)	0.00 (1.00)
Bromus tectorum	2.75 (0.10)	0.31 (0.58)	0.13 (0.73)	0.20 (0.66)	1.06 (0.29)	0.01 (0.93)	0.00 (0.97)
Elymus repens	1.00 (0.32)	1.00 (0.32)	1.00 (0.32)	1.00 (0.32)	1.00 (0.32)	1.00 (0.32)	1.00 (0.32)
Poa sp.	3.00 (0.09)*	0.33 (0.57)	0.33 (0.57)	0.33 (0.57)	0.33 (0.57)	0.33 (0.57)	0.33 (0.57)
Poa compressa	1.00 (0.32)	1.00 (0.32)	1.00 (0.32)	1.00 (0.32)	1.00 (0.32)	1.00 (0.32)	1.00 (0.32)
Triticum sp	3.24 (0.08)*	3.24 (0.08)*	0.36 (0.55)	3.24 (0.08)*	0.36 (0.55)	0.36 (0.55)	0.36 (0.55)

*Trend

Festuca sp. is one of three species: *Festuca campestris*, *Festuca Idahoensis* or *Festuca saximontana*

At a species level, I found responses to different treatments were species specific. *A. millefolium* responded positively to either no soil preparation or raking x seed, while hydro-seeding resulted in a negative response. An interaction was seed for *B. sagittata* and *G. aristata* to the double treatment of hydro-seeding and raking together. This could possibly be due to their larger seed size. *A. millefolium* seeds are small (~0.14 mg) and it’s possible they get trapped in the hydro-slurry, which may result in desiccation when the slurry dries out. It’s also possible that as the hydro-slurry dries it shrinks inhibiting newly formed roots from making contact with the soil. The fibre and tackifying agent within the slurry may also create a mat which allows little light penetration thus reducing germination. A review by Moles and Westoby (2006) established that large seeded species had an increased survival rate in conditions of shade, drought, competition and defoliation. Large seeds have the capacity to withstand short-term environmental stresses due to their stored reserves (Westoby et al. 1996) unlike smaller seeded species like *A. millefolium.* Therefore, smaller seeds may not have the carbon reserves needed in times of short-term stress such as being able to penetrate the hydro-slurry and access both the light above and soil below the slurry. Being of larger size the *B. sagittata* and *G. aristata* seeds may have the carbon stores needed to penetrate the hydro-slurry.

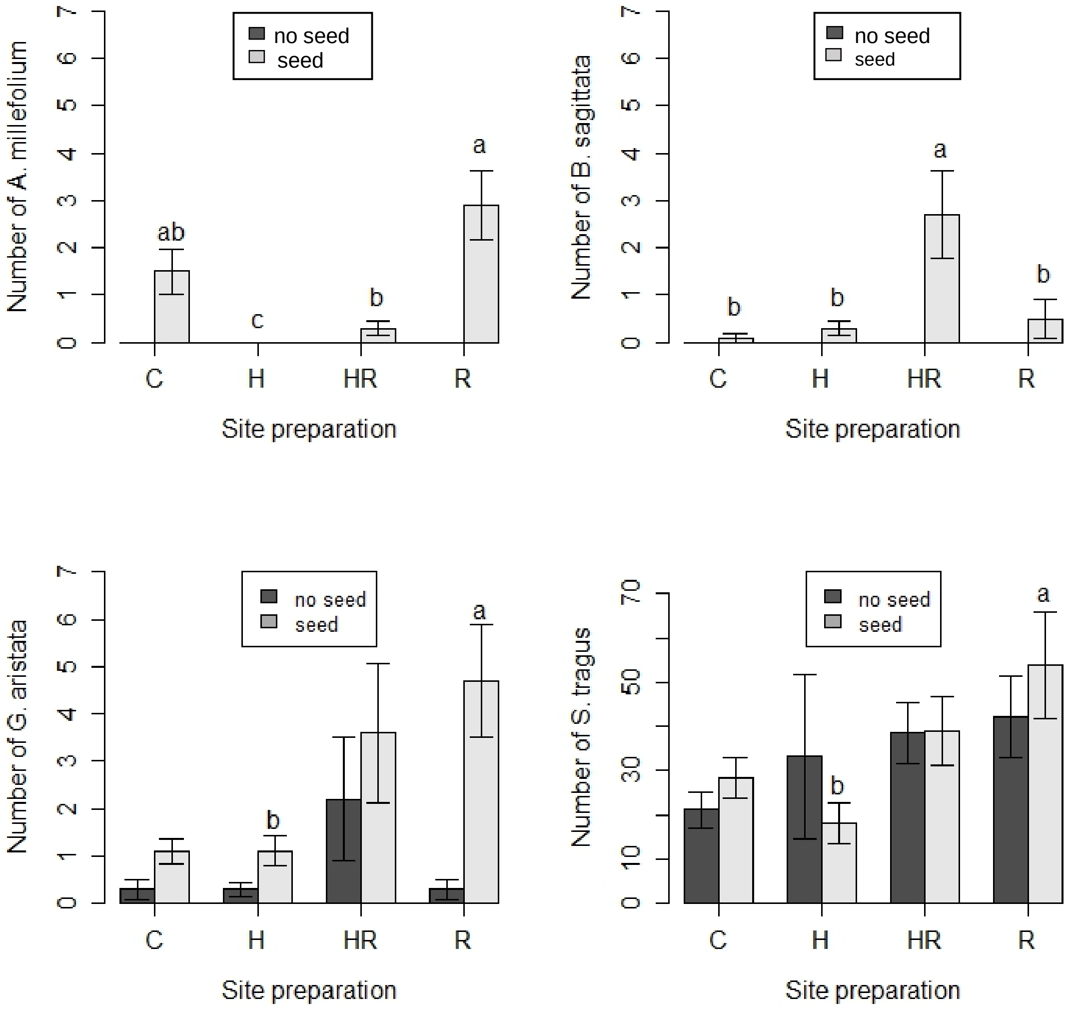

Figure C.1: Results of seeding and soil preparation on stockpiled topsoil at New Gold's New Afton Mine in the summer of 2013. Effects of soil preparation (C=control, H=hyrdo-slurry, R=raked, HR=hydro-slurry+raked) and seeding (no seed / seed) (n=80) on the number of seedlings of four species and the invasive non-native species *Salsola tragus* on stock-piled topsoil in the BC interior grasslands. Treatments labelled with different letters are significantly different ($p<0.05$). Error bars represent 95% confidence interval.

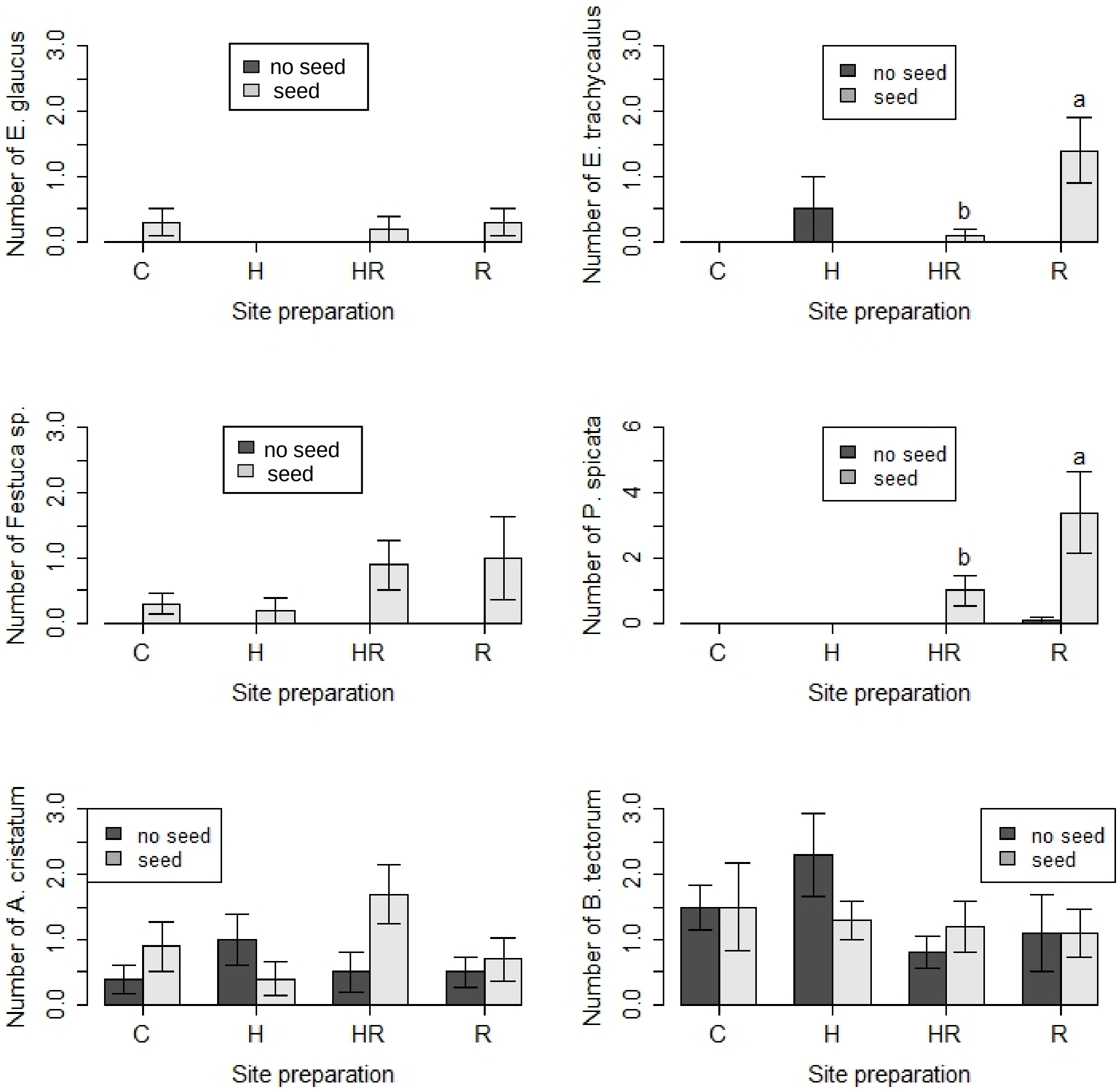

Figure C.2: Results of seeding and soil preparation on stockpile topsoil at New Gold's New Afton Mine in the summer of 2013. Effect of soil preparation (C = control, H = hydro-slurry, R = raking, HR=hydro-slurry+raking) and seeding (n=80) of native graminoid species on native graminoid seedling establishment and their resultant effect on non-native species such as *A. cristatum* and *B. tectorum* on stockpiled topsoil in the BC Interior grasslands. Treatments labelled with different letters are significantly different ($p<0.05$). Error bars represent 95% confidence interval.