UTILIZING INDIGENOUS PRESCRIBED BURNING METHODS TO RECLAIM A TAILINGS STORAGE FACILITY IN THE SOUTHERN INTERIOR OF BRITISH COLUMBIA

by

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Abstract

Mine reclamation and closure plans have historically focused on returning disturbed lands to a vegetative community, often without consideration of the pre-existing natural vegetation. The resulting plant communities are often dominated by non-desirable, long-lived, sod-forming wheat grasses often utilized for agronomic purposes due to their heartiness and ability to grow anywhere. Once established, these plant communities often dominate, restricting native species, and enter a state with little successional advancement. As mining regulatory standards and local community engagement between stakeholders have increased, the closure objective of mines have also changed. Community-engaged closure, which places more value on ecosystem function and native biodiversity, are now often the standard in Canada. Highland Valley Copper Mine has committed to working with Indigenous communities, specifically the Nlaka'pamux peoples to improve their cultural awareness and inclusion with the objective of creating sustainable benefits for Indigenous communities while also securing social license with the community to maintain business operations. Prescribed burning was traditionally used by the Nlaka'pamux people to manage their landscapes and there was interest to reintegrate fire as a management technique. A unique industry / Indigenous relationship formed to collaborate on the use of fire to reintroduce native species on a formerly reclaimed tailings storage facility. As large-scale disturbances, notably fire, have historically structured grasslands both naturally and through Indigenous cultural use, and can alter successional trajectory, I tested the effects of prescribed burning in a 24-year-old mine-reclaimed, non-desirable, grass dominated, closed tailings storage facility. Prescribed burning was applied as a means of shifting the existing plant community towards a native grassland. The objectives of this thesis were to: 1) investigate if prescribed burning can successfully act as a disturbance to transition a non-desirable, low-diversity, agronomic vegetative community to a native grassland; 2) examine the role fire intensity plays in the vegetative community when trying to establish native species under controlled conditions and; 3) investigate the level of involvement that the Nlaka'pamux peoples played in the prescribed fire project and examine the practices that industry professionals employed to connect with this community. Fire severity was modified within the greenhouse trial at three levels (high, moderate, low) and held constant (low) in the field. Fire severity adjustments were made via modifying the fuel load and time of burning per treatment. Plant community composition shifted significantly within the greenhouse because of the burning treatment. Greater effects were found in the greenhouse trial, likely due to better control of the burn, such that native species colonization was observed. These results indicate that prescribed burning can play a significant role in structuring ecosystems and allowing the re-establishment of native plant species. My results also suggest that the level of Indigenous involvement represents a relationship formed out of necessity that was demonstrated by the role that the Nlaka'pamux fulfilled throughout the implementation of the project. The findings of this study provide important considerations for both mine reclamation practices and industry / Indigenous relationships.

Keywords: Mine Reclamation, grassland restoration, prescribed fire, traditional ecological knowledge, semiarid grasslands, native species, Indigenous engagement

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Dedication

I have a lot of people who supported me through my thesis in one way or another and I dedicate my work to the people who uplifted me through all of it. First, I would like to dedicate this work to someone who entering this lab changed my life forever. Without your comradery, intense ecological debates, and endless support I would not be where I am today. I would also like to dedicate this thesis to the doctors and nurses on the intensive care and rehab unit at the Kamloops, Royal Inland Hospital as their efforts truly saved my life. Finally, I would not be where I am today without the support of my two loving parents who have pushed me to continually challenge myself and always strive for better.

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Glossary of Terms

ANPP – Above-ground net primary productivity

B.C. – British Columbia

BH – Benjamini Hochberg

GA_3 – Gibberellic acid

HBM – Hump-backed-model

OAS - Organic analytical standards

PLS – Pure live seed

RF – Random forest

TRU – Thompson Rivers University

TSF – Tailings storage facility

Chapter 1 : INTRODUCTION

Industrial scale resource extraction operations present major challenges for biodiversity and ecosystem services. The mining industry involves significant tradeoffs between ecosystem services (Costanza et al. 1997) and biodiversity conservation, as it converts multifunctional natural ecosystems into mineral provisioning landscapes (Neves et al. 2016). This conversion can be responsible for a significant temporary loss in biodiversity, largely as a result of habitat loss and altered plant communities (Percy et al. 2005, Grigg 2014). Beyond impacts to the environment, when the mining industry entered Canada at the beginning of the 19^{th} century, operations resulted in Indigenous community disruption, and dispossession of Indigenous peoples from traditional lands (Melosi 2017). This historic reality can be attributed in part to a colonialist mindset and lack of policy, regulation, and checks and balances in industry with respect to restorative or reclamation practices. This lack of policy, combined with little forethought given to the impact occurring to ecosystem services, human livelihoods and health has caused significant long lasting impacts (Virgone et al. 2018). Due to this legacy, there currently exists a vast heritage of degraded lands due to historical mining practices which displaced communities and now require restoration, reclamation, and reconciliation (Bradshaw 1997).

As mining industries faced significant amounts of scrutiny with respect to land use management, sustainability issues, and other adverse socio-environmental issues, this stimulated a response from industry to place items like sustainability reporting, and social and environmental assessments at the forefront of operations to prove due diligence is being met in order to secure a social license to operate (Azapagic 2004, Melosi 2017, Virgone et al. 2018). These efforts are applied into properly managing both impacted and natural landscapes, working within environmental policy, and collaborating with communities on end land use goals for mine closure. In the transition period between alternative and green technologies that can replace the need for resource extraction, this industry is essential to provide Canadians with modern-day comforts and economic freedom while reclamation and restoration science offer an attempt to overcome environmental problems. Today, industry has the responsibility to address impacts beyond that of the environment. Modern reclamation and reconciliation efforts have begun to encapsulate building and maintaining strong, resilient, and beneficial relationships with

Indigenous peoples and local communities to reconcile past inequities. The gold standard moving forward for industries should be to move beyond a social license to operate and into dynamic, trusted, and mutual management of the landscape with communities especially when operating on unceded Indigenous lands.

This thesis project examines a unique opportunity presented by a partnership between Teck Highland Valley Copper (HVC) Mine, and the Nlaka'pamux peoples to implement the use of prescribed fire as a reclamation tool to enhance ecosystem reclamation on disturbed mine lands. This project also represents its own unique position in science as I conducted research on the process of how the project came to be, and the effectiveness of prescribed fire to transform a successionally stalled plant community to a highly diverse grassland state. This work presents a new paradigm in which industry, stakeholders, and particularly Indigenous communities are collaborating on projects.

HISTORY AND EXTENT OF MINING IN BRITISH COLUMBIA (B.C.)

Historically when the mining industry entered Canada it promised job security and economic gain to communities that participated. This unfortunately was not the case in all circumstances. Throughout the Canadian north, mining was often attributed to toxic wastes, warning signs of abandoned mine shafts, and dispossession of Indigenous peoples and their land (Melosi 2017). This reality existed as the industry was in its infancy and a list of unknowns were present with respect to future impacts.

As the use of land to yield materials for processing and creating goods and services represent some of the most substantial changes to ecosystems, we must properly manage both our impacted and natural landscapes to ensure a positive net balance is maintained with respect to ecosystem function (Vitousek et al. 1997). With this goal in mind, reclamation and restoration ecology has emerged within the last few decades to counteract the worldwide degradation of biodiversity and ecosystem services (Hölzel et al. 2018). Environmental awareness and the full understanding of the complex chemical processes behind managing a mined landscape was not fully understood until recently. As such, many current reclamation and restoration efforts are simply lagging behind the need to effectively restore these disturbed communities to a state of no net loss with respect to ecosystem functioning, and often take much longer than expected to reach ecological targets (Ruggles et al. 2021).

Land management as it pertains to mining has been existent to some extent since 1969 in B.C. as companies have been required to reclaim all lands disturbed by mining. However, as discussed above, reclamation tends to be costly and companies would often enter bankruptcy before completing reclamation, leaving the abandoned landscape for B.C. taxpayers to deal with. Currently, the obligation to reclaim all mined lands is enforced through the *Mines Act*, and rigorous provincial standards to maintain the environment. Before starting work, a reclamation program must be created, and reviewed on an ongoing basis. In addition, a reclamation security must be paid to the province to ensure obligations are kept and money is held by the province to ensure reclamation occurs (Ministry of Energy Mines and Petroleum Resources - Mining and Minerals Division 2008). Unfortunately, reclamation efforts and mine closure still often leave behind a legacy of active management and treatment that will need to remain in perpetuity, until the environmental risks (i.e.; water quality, erosion, fugitive dust) can be managed passively (Blanchette and Lund 2016). This constant management can partially be attributed to the challenges of defining the success of restoration or reclamation for mines, in addition to the lack of passive treatment options available to industry.

Mine reclamation has been defined as a success both in policy and academia when healthy, self-sustaining ecosystems are developed on previously mined landscapes and deemed satisfactory by a chief inspector under the *Mines Act* (Garris et al. 2016, Government of British Columbia Ministry of Energy 2008). Given the lack of a clear set of measurable and enforceable reclamation criteria, paired with broad and vague inspection procedures for regulators and contractors, the formal closing of mines is both rare and costly. The province of B.C. now carries a large legacy of liability from old mines that were developed and abandoned when regulations were looser.

GIS CONSIDERATIONS

To examine the extent of mining within the province of B.C. and add context to the history of mining and reclamation status within the province, R package “bcdata” (Teucher et al. 2019) was used to download and extract spatial data from the open-source BC Data Catalogue. Extracted data and spatial layers were then imported into QGIS version 3.18.0 to be analyzed. The following data was downloaded from BC Data Catalogue:

- Permitted Mine areas – Major Mine (Samuelson 2021)
- MINFILE Production Database (Jones 2021a)
- MINFILE Inventory Database (Jones 2021b)
- First Nations Community Locations (Armstrong and Gowan 2020)

Figure 1.1 Depicts up to date and historical data downloaded from the BC Data Catalogue on currently operating major mines, historical abandoned or closed mines in need of reclamation or restoration, and First Nations communities. Analysis of this data included computations of the total land area occupied by the 37 listed major mines within the permitted mine areas dataset, in addition to total historic mines, and total ore extracted. Major mines are listed and defined by those producing coal or mineral (Government of British Columbia Ministry of Energy 2008).

The 37 listed major mines operating within B.C. as per the BC Data Catalogue represent a cumulative land area of 648 square kilometers, and have mined a total of 4.9 billion tonnes of mineral or coal material (Samuelson 2021). This metric however represents an underestimated value as the ‘Permitted Mine areas – Major Mine’ dataset is missing 35 regional mines as per the most updated, B.C. mine information webpage (BCMine Information 2021). The author of the ‘Permitted Mine areas – Major Mine’ dataset was contacted for updated information; however, the dataset access was denied as it was still under construction. Additionally, historic mine data from the ‘MINFILE Inventory’ dataset represent a total of 1696 mines, dating back from as early as 1880, with a cumulative mined total of 9 billion tonnes (Jones 2021a).

Restoration and reclamation procedures in B.C. need to be outlined in greater detail, and industry to be held to a higher standard, to ensure a legacy of abandoned mines do not continue to burden the province, and communities surrounding these mines.

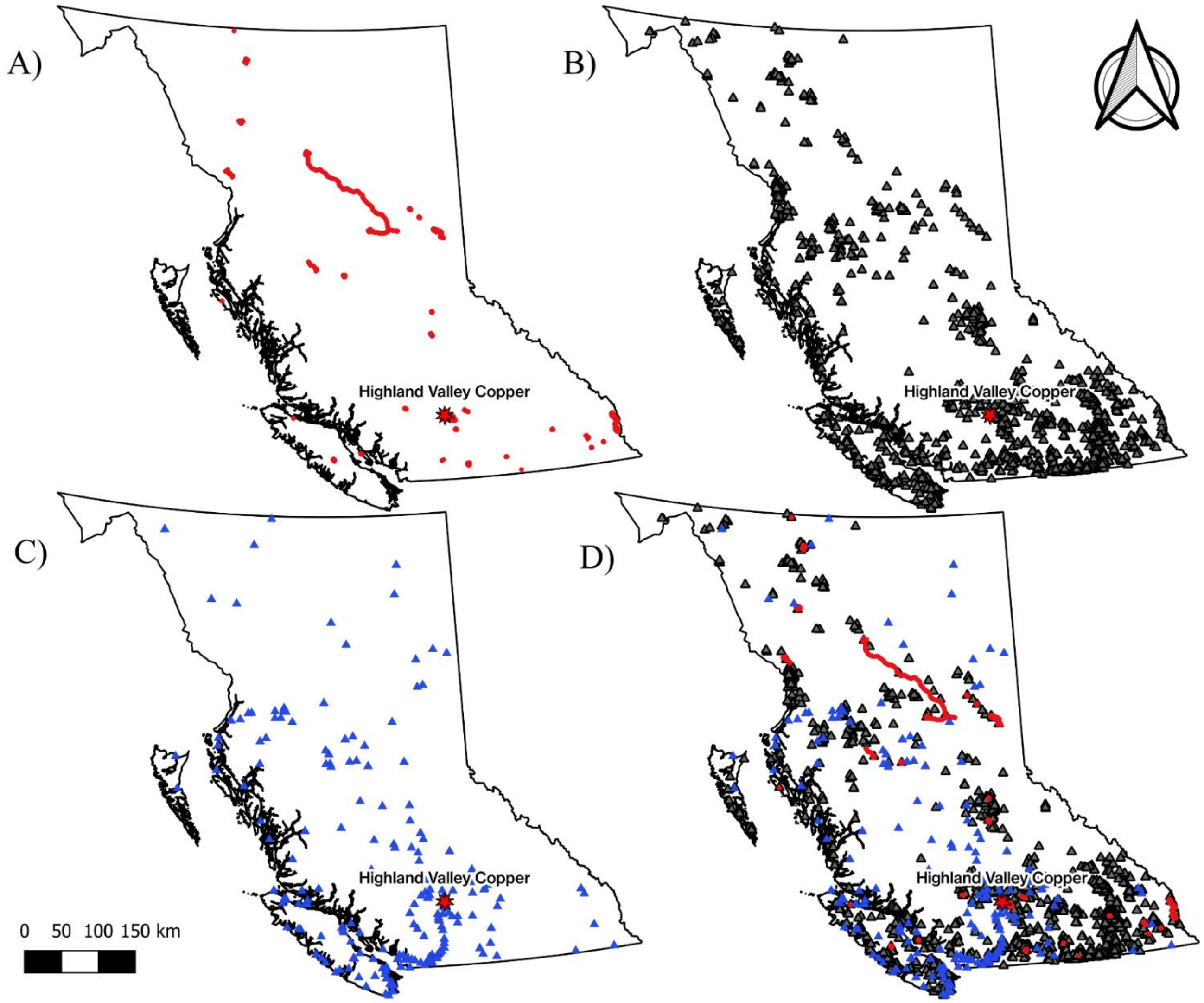


Figure 1.1. A) Extent of currently operating major mines, B) Historical mines in a state classified as: abandoned, closed, or in need of reclamation or restoration, C) First Nations communities, D) All maps overlaid. Highlighting Highland Valley Copper Mine. Map was created by Brandon Williams using QGIS version 3.18.0 using open-source data collected from BC Data Catalogue (Major Mines, MINFILE Inventory & First Nations Communities spatial data).

A BRIEF HISTORY OF COLONIALISM AND LAND MANAGEMENT IN B.C.

Indigenous peoples in Canada are estimated to represent approximately 3-5% of the total population and represent over 370 million peoples worldwide (Turner and Clifton 2009, Kumar Dhir 2016, Statistics Canada 2017). Indigenous communities in Canada and across the globe have suffered significant injustices and many continue to face marginalization, exploitation, and exclusion. This is especially present in nations in the Global South where political powers and powerful international businesses work to the disadvantage of third world state lack of policies (Hilson 2002, Munarriz 2008, Kumar Dhir 2016).

Human activities on the land inherently result in ecosystem change. Global and local scale human induced environmental changes have caused a general decline in diversity by replacing normal, predictable ecosystem functioning with a novel or unpredictable set of traits and level of function (Loreau et al. 2001). Globally, over half of the worlds land area has been converted to human-dominated land-uses (Watson et al. 2016).

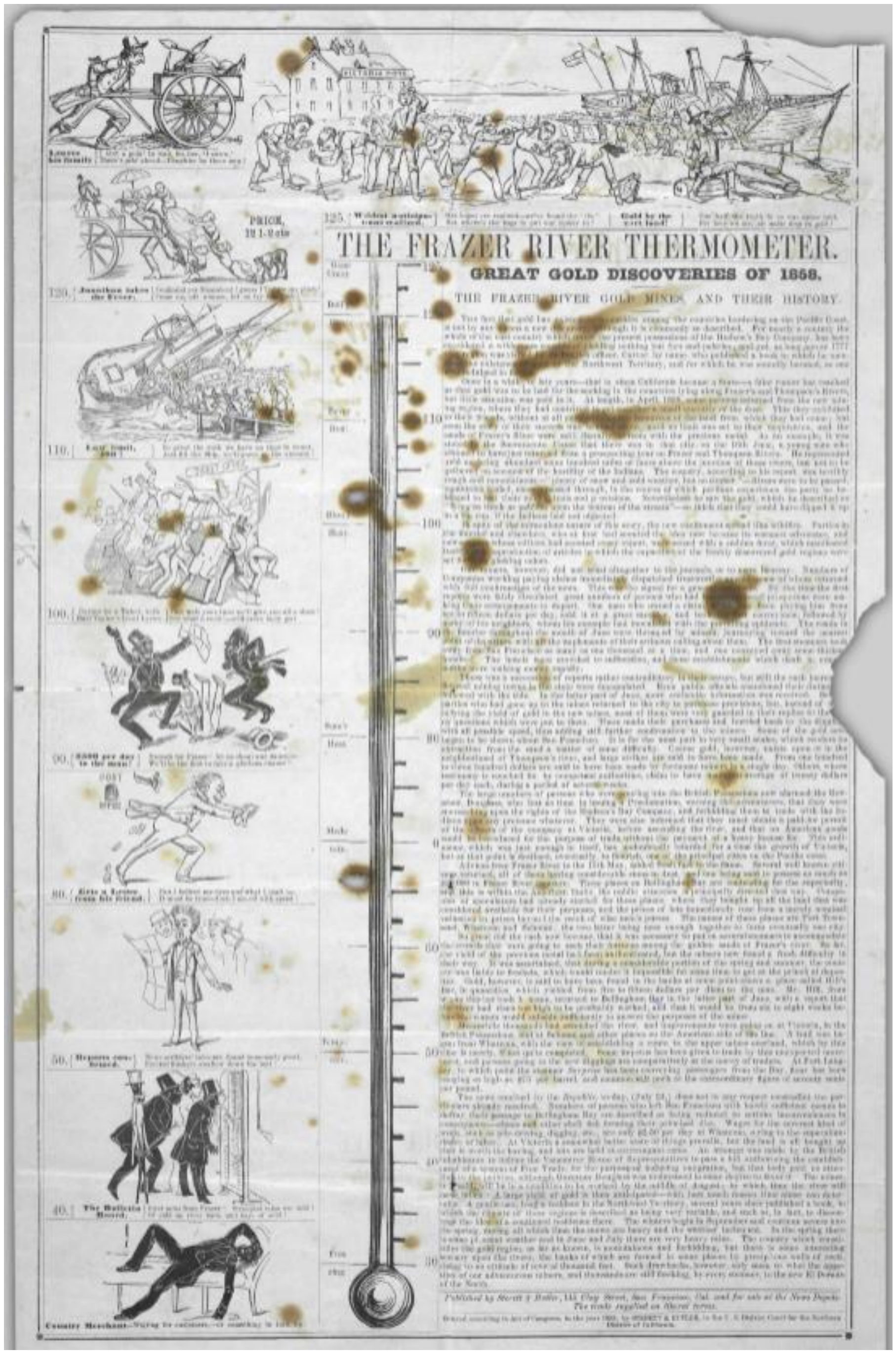
The mining industry within B.C. plays a significant role in land use and represents a significant portion of lands that need to be restored, reclaimed, or rehabilitated (Figure 1.1). The pursuit of mining and the developing mining industry has historically and currently posed a significant vector for both ecosystem and cultural change. Mining has been a part of B.C.'s economy since the mid-1800s with active coal mines on Vancouver Island and the presence of gold in the Cariboo. The onset of the Cariboo gold rush occurred when Indigenous miners discovered gold and shared the information with European explorers (Bellringer 2016, Ignace and Ignace 2017, Marshall 2018). It was the discovery and quick spread of information about the presence of gold in the Cariboo that spurred a massive immigration of approximately 23,000 Euro-American miners seeking their fortune. Reports and print articles of the 'gold frenzy' promised anywhere between $10-300 in gold to be excavated daily.

A mass migration to the Fraser River and surrounding areas was coined the "Frazer River `Fever" (Figure 1.2), and soon lead to conflicts between Euro-American miners and Nlaka'pamux Indigenous landowners when mining was protested on traditional land.

Ultimately, it was not long before the transient, self-serving population of Euro-Americans became abrasive to interactions with Indigenous peoples as conflict ensued due to access to the land for mining. These conflicts began to foster the ideology that a good Indian is a dead Indian (Marshall 2018). It is at the root of these conflicts within the 'Frazer Canyon War' and gold rush that has set the precedent for Indigenous rights in the province of B.C and the unrest that lies within the province today in regards to land use and management on unceded territory (Marshall 2018).

Mining has since expanded to all parts of the province and B.C. is now Canada's largest exporter of coal and producer of copper while producing over thirty additional industrial metals. The diversity and wealth of natural resources within B.C. poses opportunity for economic prosperity as evidenced by being the global hub for mineral exploration to over 1200 mine related companies, but also many threats ranging from environmental to cultural disruption (Marshall 2019). Despite the fact that extraction and production of these metals support current living standards and have lead to societal advancements, the cost often comes to the detriment of the environment, ecosystems, and deleterious impacts on human health, culture, and communities (Virgone et al. 2018). To further complicate matters, significant challenges arise as governments and communities are faced with a dilemma on how to find a balance between the needs for resource development and biodiversity conservation, while meeting demands for mineral commodities (Sengupta 1993, Grigg 2014).

Currently within B.C., legislation has been passed that confirms the 'United Nations Declaration on the Rights of Indigenous Peoples (UN Declaration)' (Government of British Columbia 2019). This framework towards reconciliation of Indigenous rights with the interests of Canadian society places a duty on the crown to 'consult and accommodate Indigenous peoples' for mining, mineral exploration, as well as oil and gas. This however does not explicitly protect Indigenous rights but rather mandates the procedural duty to consult and accommodate. A fundamental flaw however does not address or respect Indigenous rights fully as infringement can be justified, so long as consultation was upheld under section 35 of the *Canadian Constitution Act* (Horowitz et al. 2018).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THE FRAZER RIVER THERMOMETER.

GREAT GOLD DISCOVERIES OF 1858.

THE FRAZER RIVER GOLD MINES AND THEIR HISTORY.

Figure 1.2. Newspaper article printed in San Francisco on rumors of the gold rush highlighting the Frazer River thermometer and the great gold discoveries of 1858 (Sterrett & Butler 1858)

The implications of industrial expansions have moved beyond environmental damage and have affected many communities and ways of living since the onset of the goldrush within B.C. as individuals and industries began to seek rights to extraction and settled land in traditional Indigenous territories. As a result, Indigenous communities have been placed at risk by dispossession from their traditional lands, loss of culture, and sense of place (Palmer 2005, Fernandez and Silver 2017). As global demands for resources increase, industry sectors like mining will need to continue to expand restoration and reclamation efforts to support sustainable development while surpassing ecological objectives and work towards reclaiming and restoring good faith with local and Indigenous communities to preserve culture and protect the land. The task for the future is moving beyond the approach of simply receiving social license to operate, and instead collaboratively build social enterprise with common objectives.

CHALLENGES IN RECLAIMAING MINED ECOSYSTEMS

In the pursuit to reclaim ecosystems within a mine setting there are many external factors that place limits on the reconstruction of a plant community. Restoration and reclamation following the mining process is both complex and challenging due to various biotic and abiotic factors (Turner et al. 2006, Gasch et al. 2014). One of the first steps in restoration or reclamation of these lands is typically revegetation. Outside of the semi-arid environment and climate conditions that exert the primary control of plant productivity and composition, many characteristics of mine wastes often provide unfavorable conditions to successful vegetation establishment, notably the levels of residual heavy metals, low nutrient status, poor physical structure of soils, and extreme pH values (Tordoff et al. 2000, Sample and Barlow 2013). The combination and interactive effects of unfavorable substrate, paired with low annual precipitation can compound the challenges with restoration in higher temperature, semi-arid mine lands, and poses a unique challenge as these landscapes are already attributed with a lower richness and diversity of species (Osman and Barakbah 2011).

One of the major challenges to deal with when reclaiming or restoring function to disturbed mine sites is the lack of volume and degradation of topsoil over time, and an overabundance of mine wastes. Due to the nature of mining, stripping of the soil and vegetation is necessary. Soils are then stockpiled during the life of operation for the mine, and have been found to deteriorate in quality, ultimately becoming unfertile by the time of mine closure or use (Ghose 2004). While topsoil is low in quantity, mine tailings waste is in large abundance. Mine tailings present one of the most harmful and longest lasting environmental liabilities that needs to be managed (Young et al. 2015). As such, it is a high priority for mines to manage their tailings from entering groundwaters, rivers and lakes, and reducing wind travel. Management techniques vary from riverine disposal, submarine disposal, wetland retention, backfilling, and dry stacking storage (Lottermoser 2011). As every ton of metal extracted, typically generates a ton of waste, and often orders of magnitude more due to inefficiencies there is a large need to manage these tailings in some way (Lottermoser 2011, Adiansyah et al. 2015). Due to site specific geology, tailings compositions vary greatly in metal composition but are universal with respect to being low in organic matter and essential plant nutrients, and are often fine textured sandy material (Sample and Barlow 2013, Kossoff et al. 2014).

Tailings pose a significant risk as they often contain potentially hazardous contaminants and trace heavy metals. In semi-arid and arid environments, dry stacking storage is a common technique and desirable for both economical and reclamation purposes. This process entails filtered tailings emerging from a processing facility in the form of a slurry that are then placed, spread, and compacted to form a stable tailings “dry stack” (Figure 1.3). This process requires no dam to be built to retain the tailings and no water supply to be maintained which is advantageous considering water conservation and capital costs associated with geotechnical design (Davies 2011).

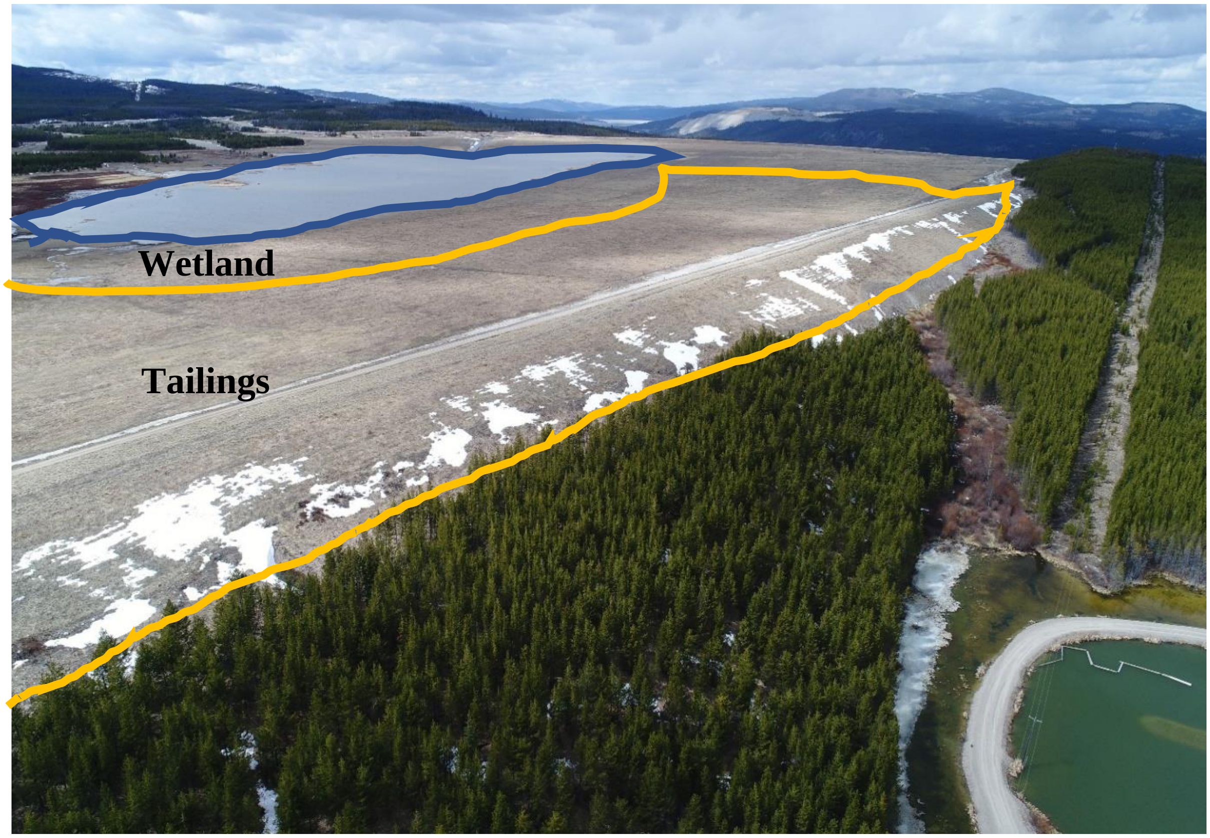

Figure 1.3. Overview image of the closed tailings facility (Highmont Tailings) located at Highland Valley Copper Mine located in British Columbia, Canada

One main advantage of dry stack tailings is that progressive reclamation can occur with closure of the facility. However, with arid conditions, wind dispersion and water erosion of fine particle tailings poses a large risk. To combat this issue, phytostabilization and revegetation is often used to reduce wind contamination and erosion (Mendez and Maier 2008, Davies 2011). Historically, the revegetation of these closed tailings facilities have not utilized native plant species and instead utilized agronomic grass species, and have not addressed a long term succession plan for the plant community (Mendez and Maier 2008). Due to the difficulty in reclaiming more complex ecosystems such as forests, and often higher costs associated with the work, most disturbed sites are reclaimed to a grassland state. However, most reclaimed grasslands are often characterized by a low diversity, non-native, agronomic, or exotic species (Swab et al. 2017). This problem can partially be attributed to the large scale of reclamation operations and limited options of native seed compared with large quantities of agronomic seed availability, low price, and heartiness or ease of establishment of many of these species on harsh mine spoils (Burton and Burton 2002).

The practice of surface-mine reclamation and creation of artificial grasslands is evident in the Appalachian region and midwestern United States where these grasslands comprise a significant portion of the restored landscape (Brothers 1990, Swab et al. 2017). These lands were reclaimed in the 1970's, and at this time converged towards the establishment of monoculture or low diversity grasslands dominated by hardy, non-native, forage crops. Furthermore, reclamation was guided by two objectives; minimizing cost as most companies did not budget funds for reclamation, and simply establishing vegetative cover (Brothers 1990). Currently, many approaches to mine reclamation still use non-native or exotic species as a cover crop and do not utilize native species' local adaptations to attain the same goal. Incorporating specific, well adapted native plants into reclamation can increase the biodiversity of the ecosystem, and potentially improve soil conditions more quickly than non-native plants (Swab et al. 2017). Even as these landscapes have been vegetatively recovered, ecosystem functioning, and biodiversity measures are nowhere near current

Figure 1.4 Twenty-five-year-old reclaimed vegetative cover crop landscape represented by a monoculture mosaic of non-desirable, agronomic grass species such as *Bromus inermis*, *Elymus lanceolatus,* and *Thinopyrum intermedium* located at Highmont Tailings, Highland Valley Copper Mine, British Columbia, Canada.

objectives held by stakeholders, industry, government regulators, and Indigenous communities.

In the case of HVC, as evidenced by Figure 1.4., historical revegetation practices have used hearty, fast growing, agronomic species to achieve their goal of revegetating mine-spoils. However, the established agronomic plant species hinder the establishment of native plants through competitive exclusion (Young et al. 2015).

Restoration of mine lands is a complex issue with biotic, abiotic, and social factors all playing a role. The new ecological problem however lies within the fact that reclamation and closure plans have historically ignored pre-existing natural vegetation and opted for a hearty, fast-growing, non-desirable vegetative monocrop cover on mine-spoils. The disparity between historical practice and new restoration and reclamation standards has now placed new challenges to reclaim these already burdened lands to a more biodiverse ecosystem state on established vegetative communities. As evidenced by Figure 1.1, a vast array of mine sites across B.C. need further restoration or reclamation and may already be composed of non-native communities due to historical practices. The problem ahead is with the recovery of native communities in fields dominated by fast-growing exotic species, which is often impeded by the competitive advantages of the established community (Yahdjian et al. 2017). As the availability of native plant seed increases, combined with the positive effects and viability of using natives on disturbed mine lands, it is clear that native plants can increase ecosystem functioning, however a mechanism to assist these species establish is also a question that needs to be addressed. A mechanism to transition these communities on mine lands may be prescribed fire and represents a significant knowledge gap within existing scientific literature that my research aims to examine.

PRESCRIBED FIRE TO FACCILITATE ECOSYSTEM RECOVERY IN GRASSLANDS

In natural ecosystems, disturbances, notably fire, have major positive and negative impacts on ecosystems as they can influence the abundance and diversity of species, nutrient cycling, biomass accumulation, primary production and other processes (Pulsford et al. 2016). In semi-arid grasslands the relationship between prescribed fire and plant community response generally does not follow a uniform consensus on the post-fire effects on plant communities (Rau et al. 2008). Overall effects of burning on plant and soil interactions may differ due to plant cover types, and differences in fine and woody fuels available which can directly affect fire severity (Rau et al. 2008).

Generally, fire can modify relationships among species on the landscape and change dominance in a community due to species specific responses to changes in soil moisture, nitrogen (N) cycling, and direct effects on meristem mortality (Ghermandi et al. 2004, Augustine et al. 2014). Fire in semi-arid and arid ecosystems has shown to increase the availability of inorganic N in the first-year post-burn, as well as for extended periods beyond the burn (Rau et al. 2007). This increase in plant available nitrogen can influence regrowth, native species seedling establishment, and establishment of annual plants. These factors ultimately aid in site recovery (Rau et al. 2007, Augustine et al. 2014), therefore making it beneficial in reclamation of mine spoils where nitrogen is limited and it is an objective to change trajectory of the plant community.

Grasslands also benefit from fire in arid and semi-arid environments where microbes cannot readily breakdown accumulated plant litter (Brockway et al. 2002). A secondary benefit of litter removal or consumption of accumulated litter by fire is a result that often favors establishment of new species due to subsequent release of nutrients immobilized within the dead plant tissue, increased solar radiation to the ground, and allowing a period of reduced competition for new species to enter (Brockway et al., 2002, Scheintaub et al. 2009). Additionally, in highly productive sites, litter accumulation that is left in a state without disturbance or some form of reduction may ultimately restrict above ground net primary productivity (ANPP), species richness, and favor tall lived species reducing functional diversity in life form (Peco et al. 2012).

Plant community responses to prescribed fire within the literature regarding community composition, cover, and diversity have been presented as net neutral, positive, or negative based on different studies. Scheintaub et al. (2009) found that spring burning within a semi-arid shortgrass steppe community resulted in an overall decrease in ANPP by 20% in burned vs unburned controls. However, as ANPP decreased through perennial and annual grass productivity, perennial forb production and total vegetative cover increased in response to fire. Additionally, forb response to fire is most consistent with regard to increasing in total cover after fire which remains consistent within literature presented by Ruthven et al. (2000) where forb coverage was greater on burned than unburned sites. This increase in cover is likely due to an interaction between death of the apical meristem during spring burning in select species which removes growth inhibition and spurs formation of new shoots (Forest Service - Rocky Mountain Research Station 2000). In contrast to this, Augustine et al. (2014) found that annual burning significantly reduced cool season (C_3) plant production and forb cover but did not affect warm season (C_4) plant production. Positive plant community responses including increases in plant species richness and plant cover have been historically noted in semi-arid grasslands by Kirsch et al. (1972) with a steep increase in plant richness post-fire from 38 to 69 species. More notably, McDonald et al. (2011) found that prescribed fire reduced the abundance of dominant non-native grasses, while increasing the abundance and diversity of native grasses and herbaceous dicotyledons. For these reasons, the introduction of prescribed fire represents a promising opportunity to overcome some of the challenges presented above with respect to recycling nutrients to nutrient limited tailings, while also allowing for reduced competition and new species to enter the ecosystem.

HISTORY OF INDIGENOUS USE OF FIRE & CHANGING LANDSCAPES

The history of fire on the landscape within B.C. presents a complicated and ever-changing path forward as we continue to modify our ecosystems and the way we manage our lands and the way we think. As the semi-arid grasslands of the interior receive typically less than 400 mm of rainfall on average, the low precipitation patterns paired with warm summer temperatures and moderate to high winds create a landscape that is naturally conducive to wildfire (Environment and Climate Change Canada 2021). Prescribed burning as the purposeful application of fire to the landscape is regularly used in the management of fire-prone ecosystems worldwide (Penman et al. 2011). The semi-arid grasslands of B.C. present a prehistoric history of anthropogenic burning by Indigenous peoples that ranges from roughly 7000 years before present (Blackstock and McAllister 2004, Lewis et al. 2018) to shortly after European settlement in B.C. in the early 1900's. Prescribed burning by Indigenous communities then was halted as European interest in the forest complex no longer permitted burning of any kind (Lewis et al. 2018). This Euro-American view directly clashed with Indigenous traditional knowledge that utilized the benefits of prescribed burning (Kimmerer and Lake 2001).

The common thought that Indigenous peoples lived a commonly circulated misconception about minimal to no level of land use and management contrasts with the reality that Indigenous peoples practiced a philosophy of respect for natural resource management that allowed for a sustainable lifestyle that maximized productivity of food and materials (Turner et al. 2000, Kimmerer and Lake 2001). Land management practices such as foraging and harvesting that aided in the maintenance and enhancement of their lands, water, and resources to support sustainable living is derived from generations of knowledge being passed on from experimentation and observation (Turner et al. 2000). Indigenous use of fire represents one of these practices that was utilized by many Indigenous peoples throughout North America and B.C. (Kimmerer and Lake 2001) to meet ecological-based goals of selecting for desirable vegetation, and as a means of maintaining important grazing habitats by controlling tree encroachment and managing forest fuel loads (Turner et al. 2000, Storm and Shebitz 2006, Lewis et al. 2018).

As the landscape of B.C. changes due to environmental and social factors, like the implementation of fire exclusion in the early 1900's, significant changes in the ecological and cultural conditions across the province have occurred and are readily visible upon inspection of our vulnerable grasslands ecosystems. Indigenous Elders from the Nlaka'pamux (Thompson), Silx (Okanagan), Secwepemc (Shuswap), Stl'atl'imx (Lillooet) and Ts'ilquot'in (Chilcotin) nations from the southern interior of B.C., have recalled and reminisced when grasses were belly-high to a horse and the state of the grasslands were thriving (Blackstock and McAllister 2004). Many bunchgrass biogeoclimatic zones that once naturally presented a high plant diversity to support ungulate species and complex foodways for Indigenous communities have now been replaced with woody encroachment of sagebrush (*Artemisia tridentata*) and ponderosa pine (*Pinus ponderosa*). These zones are now at risk of shrinking in size and diversity (Fuhlendorf et al. 2008, Lewis et al. 2018). Cumulative effects of overgrazing by cattle and fire exclusion have strongly interacted to cause shifts in the plant community composition to be less productive and comprised of more ephemeral species. These changes also affect the habitat of grassland specialists and keystone species as these areas are slowly converted into shrublands and forests (Fuhlendorf et al. 2008, Symstad and Leis 2017).

Fire exclusion has also led to a shift in Indigenous community dynamics and the loss of important cultural uses of ancestral lands. Currently, prescribed burning for many Indigenous cultures is significantly reduced as it can only be completed under strict government consent and typically only under use for human asset protection through reducing fuel loads (Penman et al. 2011, Lewis et al. 2018). However, a paradigm shift has occurred as larger incidences of destructive fires are increasing because of mismanagement and fire suppression efforts (Flannigan et al. 2009). Additionally, larger quantities of western scientific literature are surfacing that supports the use of prescribed burning as a management technique, to aid in the ecological health of fire derived ecosystems and as an ecosystem management strategy (Sutherland 2019). This resulting change in thinking has come full circle as Indigenous fire management practices are now being recognized and adapted as an effective way to manage our landscapes (Nikolakis and Roberts 2020).

As the grasslands of BC have evolved naturally and anthropogenically in a fire-driven ecosystem, the reintroduction of prescribed burning offers an approach to manage our landscapes while fostering positive ecological and cultural benefits.

THESIS RESEARCH OBJECTIVES

This thesis examines a unique project and partnership between Teck Highland Valley Copper (HVC) and the Nlaka'pamux peoples. Part of the building of this relationship rests on the intent to collaborate on the goal of reclaiming and restoring ecosystem function and the traditional land uses back to a pre-mined landscape to the extent possible given the impacts mining has created. This collaboration involves the implementation of Indigenous traditional ecological knowledge of prescribed burning, blended with contemporary ecological theory pertaining to plant community dynamics. The following three research questions were posed:

1) What level of involvement have the Nlaka'pamux peoples had in the prescribed fire project and what practices have industry professionals employed to connect with these communities?
2) What role does fire intensity play in the vegetative community when trying to establish native species under controlled conditions?
3) Can prescribed fire successfully act as a disturbance to transition a non-desirable, low-diversity, agronomic vegetative community to a native grassland?

Each research question is paired with an experimental procedure, and associated methodology aimed at answering the specific question.

To address the above questions, I have conducted a three-part study involving a critical analysis of the industry / Indigenous relationship (Chapter 2), a prescribed burning field study (Chapter 3), and a mesocosm prescribed burning greenhouse study (Chapter 4). I then provide the management implications to consider (Chapter 5).

The objectives of the field study are three-fold: 1) to examine the role prescribed fire plays in the vegetative community with respect to biodiversity measures, 2) to examine how prescribed fire modifies soil nutrient cycling with respect to total carbon (C) , total nitrogen, and C:N ratio, and 3) to examine if differential establishment responses occurred between seven native grassland species in post-fire conditions. The objectives of the greenhouse study are three-fold: 1) to examine the role fire intensity plays in the vegetative community when trying to establish native species under controlled conditions, 2) to examine how fire intensity and disturbance treatment modify soil nutrients such as total carbon, total nitrogen, and C:N ratio, and 3) examine if differential establishment responses occur between six selected native grassland species in post-fire conditions.

Additionally, in order to address the third question of interest I conducted a critical analysis of how the industry / Indigenous working partnership came to be with respect to the fire project. More specifically, through the use of semi-structured interviews my objective was to examine: 1) What level of involvement the Nlaka'pamux peoples had in the prescribed fire project and what practices industry professionals employed to connect with these communities? The results of this study will contribute to the body of contemporary ecological knowledge regarding novel techniques used in reclaiming biodiverse native bunchgrass grasslands to low diversity, agronomic dominated mined environments. These results will benefit reclamation practitioners and researchers in enhancing biodiversity to low diversity sites. I also examined and outline the history of mining within B.C. with respect to land use, and I provide context on the use of prescribed burning through its use traditionally with Indigenous peoples while also introducing other supporting literature to support its use as a proposed reclamation tool (Chapter 1).

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Chapter 2 : EXAMINING INDIGENOUS INVOLVEMENT WITHIN THE PRESCRIBED BURNING TRIALS CONDUCTED AT HIGHLAND VALLEY COPPER MINE

IINTRODUCTION

The extent of mining impacts on Indigenous communities vary on the approach of the mining company, regulatory regimes, socio-economic conditions, and Indigenous community response (Horowitz et al. 2018). The transformative nature of mine operations has often resulted in the displacement of Indigenous communities from traditional territories, and the curbing of traditional land uses. In some cases, these legacies have formed levels of distrust of the mining industry and their practices (Melosi 2017). For Indigenous communities located adjacent or in proximity to mines, many concerns arise from the environmental risks associated with mining. Most commonly, downstream ecological effects from the mine are of great concern that result in the community holding a decreased confidence in freshwater quality and their terrestrial ecosystems. This ultimately results in the displacement of Indigenous land uses (Lottermoser 2011, Horowitz et al. 2018).

Historically, for mines operating on Indigenous territories, where communities have complex and significant connection to the land, issues of downstream effects of mining were often excluded from planning and decision making. In Canada, due to the volatility of mineral markets, paired with a lack of policy for managing abandoned lands, a legacy exists of abandoned and contaminated sites that caused negative socio-economic and environmental impacts for nearby communities (Monosky and Keeling 2021). As public demands for socially responsible and ecologically viable industrial practices have increased, mine companies have responded by representing environmental planning, reclamation and restoration of disturbed lands and Indigenous livelihoods at the forefront of mine operations (Fonseca et al. 2014). Given the unique circumstances of mining, such that ore bodies may only be located in particular areas, it is in the best interest of extraction companies to maintain a social license to operate and engage with communities to gain access to land and resources. Furthermore, changes in institutional and legislative reforms within the province of B.C. have resulted in the promotion of consent-based and collaborative approaches that consider Indigenous peoples, their land, culture, and economies (Allard and Curran 2021). Many mine companies in B.C. are embracing a task of responsibility to work with Indigenous communities. One way that industry has attempted to engage with Indigenous communities is utilizing and integrating traditional ecological knowledge.

Indigenous peoples of the southern interior of B.C. have developed sustainable management practices since time immemorial that utilize what we understand today as fundamental ecological principles (Turner et al. 2000). This knowledge informs a way of understanding and an intimate connection to the land that facilitated a belief system that imposed social and spiritual sanctions on people who did not treat all living things sustainably and with respect. All interactions with the environment are grounded in respect for changing ecologies, and fine tuning ways to sustainably harvest fish, plants, and animals to ensure sustainable yield for the future (Ignace and Ignace 2017). This type of natural resource management style and philosophy is becoming a focus of attention for many industries, professionals, and researchers that seek ways to advocate for biodiversity and provide models for sustainable practices that extend beyond western ways of knowing. Traditional ecological knowledge and wisdom have also been recognized as equivalents and complementary to western scientific knowledge. This has encouraged western researchers to apply traditional ecological knowledge (Turner et al. 2000).

Highland Valley Copper Mine (HVC), located within British Columbia (B.C.), Canada, operates within traditional Nlaka'pamux territory. The traditional territory of the Nlaka'pamux is centered around the Nicola Valley and stretches from the Fraser Canyon and Princeton in the south to Cache Creek and Kamloops in the north (Figure 2.1) (British Columbia Assembly of First Nations 2020, Cold Water Indian Band 2021).

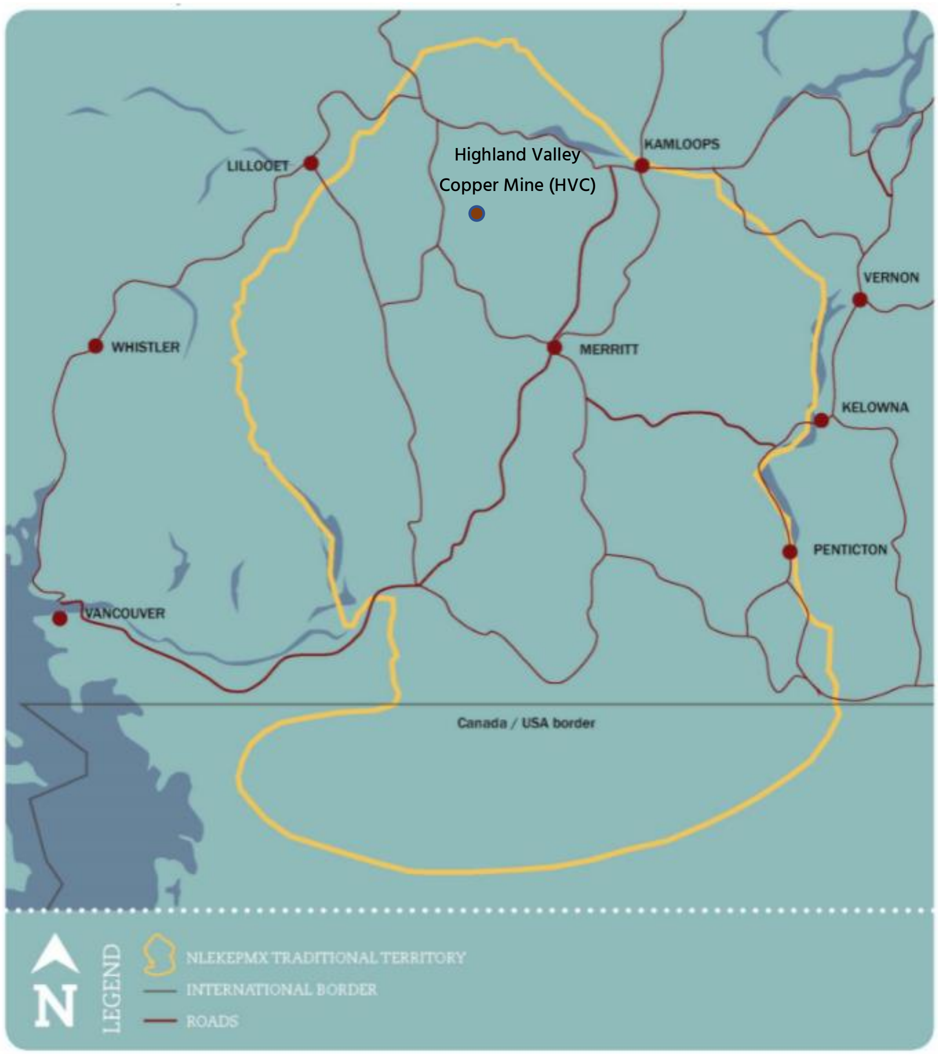

Figure 2.1 Nlaka'pamux traditional territory within B.C. amended with approximate location of Highland Valley Copper Mine (HVC) (Cold Water Indian Band, 2021)

Highland Valley Copper Mine has committed to work with Indigenous communities to improve their cultural awareness and inclusion with the objective of creating sustainable benefits for Indigenous communities. Operations at HVC are developing programs to build meaningful relationships and incorporate the interests of the local Nlaka'pamux Nation, by applying people-centered frameworks and principles of dialogue to strengthen relationships with local Indigenous peoples (Teck 2021). An example of HVC engagement with local Indigenous communities is a prescribed fire trial that was implemented in partnership with the Nlaka'pamux Nation to incorporate traditional Indigenous knowledge of prescribed fire into reclamation practices. This collaboration between traditional ecological knowledge and western scientific knowledge to manage landscapes represents a promising strategy to reconcile past inequities while also restoring the ecosystems we all depend on. The maintenance and legitimacy of these relationships are sometimes questioned as Bernauer and Slowey (2020) argue that when commodity prices are low, operations shift towards restoring profitability while rolling back on other commitments such as environmental and community commitments. This research aims to examine the level of Indigenous involvement, while also assessing how project practitioners that were instrumental to the project considered the needs and perspectives of the Nlaka'pamux community when creating and conducting the prescribed fire trials at the Highland Valley Copper Mine.

METHODOLOGICAL CONSIDERATIONS AND RESEARCH METHODS

It should also be noted that not all Indigenous communities may have these same experiences, and specific knowledge offerings should be understood within their own cultural context, place on the land, and way of knowing apart from western ideologies and science (Kovach 2009). I acknowledge that the scope of this analysis and overall examination has been completed on western terms, without any direct Indigenous participation. I also acknowledge that my analysis and consideration of this project is one that has a limited scope and only represents data accessed through the interview process.

Semi-structured interviews are valued for their use in many different research fields. The unique variability in questions and prompts aims to draw participants more fully into the topic under study (Rabionet 2011). Prompts typically include open-ended and theoretically driven questions that aim to elicit data that is grounded in the experience of the participants and guided by the constructs presented by whoever is conducting the research (Galletta 2012). The semi-structured interview nature allows for the interviewee to engage in specific topics that were of interest to them while facilitating time for reflection and digression from listed questions. This research method was selected due to its compatibility with Indigenous Methodologies and oral foundation that remains highly significant in Indigenous cultures, including the use of story and conversation to support intergenerational knowledge exchange (Ignace and Ignace 2017, Kovach 2012). Interviews were conducted under TRU human ethics application (#100999).

I used qualitative semi-structured interviews with four non-Indigenous mine industry stakeholders who were instrumental in project initialization and working with the Nlaka’pamux community. A total of four, in-depth interviews were completed with the use of an interview guide to direct the topics of discussion (Appendix A). Each interview was approximately 60 minutes in length, with a total cumulative recording time of 288 minutes. All highlighted quotes for the purposes of this research have been kept anonymous. Our discussions were centered on the following subjects or themes of inquiry: 1) Processes to build Indigenous / industry relationships; 2) Limitations to the prescribed fire project and Indigenous engagement; and 3); Opportunities to improve future engagement and collaboration.

All interview data was recorded and transcribed verbatim for analysis. A transcript of each respective interview was sent to each participant for final review prior to use. Of these interviews, three participants worked for the primary consulting company (Integral Ecology Group) in charge of the prescribed fire project management. Integral Ecology Group (IEG) assumed a major project role and was responsible for running workshops for HVC (Teck), conducting the Indigenous outreach, research design, field data collection, and project management the day of the prescribed burning.

Participant #1 is a landscape ethnoecologist with IEG and works with both the reclamation and culture team where he primarily works with integrating Indigenous knowledge with scientific data. Participant #1 has experience working with Indigenous peoples in Taiwan where he studied ethnoecological classification of mountain forests and compared Indigenous knowledge systems to ecological classification systems. Participant #2 is an ecologist who began working with Indigenous communities and the mining industry when she started consulting with IEG in 2011. Participant #2 expressed interest in working with Indigenous communities and having the opportunity to learn from them. Participant #3 is an ecologist and soil scientist. Participant #3 has a long-standing history of working with HVC since 1998 on various contracting services that are focused on their reclamation programs. Participant #4 an employee at HVC and supervises a team of individuals within the environment department and conducts work for permitting and reclamation at the mine. Participant #4 has a background in forestry and has played a role at

HVC to advocate for early planning and closure of mine sites. Participant #4 also spends a significant portion of time coordinating Indigenous technical working groups and has worked for HVC for 15 years. It must be noted here that individuals were not recruited for interviews from the HVC community team, the Indigenous contractors that worked on the study or technical representatives from the groups HVC engages with.

Table 2-1. Overview of semi-structured interview research participants for interviews conducted in 2020

Participant #	Interview Date	Affiliation	Position
1	July 14, 2020	Consultant, Integral Ecology Group Ltd.	Non-Indigenous, Landscape Ethnoecologist, Specialty lies within braiding reclamation and culture
2	July 14, 2020	Consultant, Integral Ecology Group Ltd.	Non-Indigenous, Ecologist, Liaising and engaging with Indigenous peoples on regulatory and planning initiatives
3	Aug 18, 2020	Consultant, Integral Ecology Group Ltd.	Non-Indigenous, Owner of Integral Ecology Group, Ecologist, Specialty lies within reclamation and restoration of mined landscapes with 20+ years of experience
4	Aug 31, 2020	HVC Employee, Teck Resources Limited, Highland Valley Copper Mine	Non-Indigenous, Environment Supervisor, Supervises and leads the environment, permitting, and reclamation team and coordinates with Indigenous technical working groups

CREATING A RELATIONSHIP OUT OF NECESSITY

From the fur trade to the present, the extractive industry within Canada has always been a key driver of the economy. However, extractive industries, and the mining industry specifically, carry forward a set of processes that is premised upon and requires Indigenous dispossession historically, and now Indigenous partnership to gain access to land and resources of interest (Bernauer and Slowey 2020). Communities interested in maintaining a traditional relationship to their land amidst natural resource extraction and land development have had to continually struggle for their rights to participate in decision making (O'Faircheallaigh and Corbett 2005). Even though mining has operated within the province of B.C. since the mid-1800s, it was not until the early 21st century that Indigenous peoples have secured a significant role in environmental management with the passing of the United Nations Declaration on the Rights of Indigenous Peoples (UN Declaration). This declaration places a duty on the crown to consult and accommodate Indigenous peoples for mining, mineral, and oil and gas exploration (Marshall 2018).

The interviews support research in this specific context around missed opportunities to acknowledge and accommodate community and Indigenous peoples interests at HVC up until about the time that the idea of corporate social responsibility and growing public awareness of the human impacts on the environment came under larger public scrutiny within B.C. All participants within the study were found to hold a high degree of optimism to enhancing engagement with Indigenous peoples and improving reclamation processes by learning what different forms of knowledge can offer to improve land-use management. The participants in the study all also directly referred to the idea of an industry / Indigenous relationship that served multiple objectives. I discuss the idea that despite the formation of these relationships being viewed as a positive step forward, several constraints still exist to produce optimal collaborations.

Throughout all the interviews it was evident that up until around the year 2012, the capacity for Indigenous engagement was low. This being said, the capacity at the community level to engage also plays a factor as industry / Indigenous engagements increased. Participant #3 indicated, "I had never even heard the word Nlaka'pamux [until] say 2012, [when] it became very clear that

[HVC] was taking seriously the aspect of reclamation…and looking to establish a collaborative relationship with the Nlaka'pamux" (2020). It should be noted that this quote represents a limited scope into the direct community operations at HVC but does speak in some capacity to the relevancy of shifting paradigms with conducting engagement. The fact that this work proposal and scope of work also was granted to individuals (consultants) with expertise in the area speaks to HVC beginning to take note of the importance to engage these communities to further support mine operations. Participant #3 also explained that "strong leadership throughout the [HVC] environment and community department, hold a high degree of integrity and commitment towards speaking honestly about the various damages that had been caused by the mine and extending a desire to collaborate on repairing at least some of that damage" (2020). It was expressed explicitly that outreach towards engaging with the Nlaka'pamux, or other Indigenous and local communities for that matter takes form through impact benefit agreements and various committees like technical working groups. Meetings with these groups help assist the mine to ensure any concerns brought forward do not compromise the ability of the mine to receive permits. Participant #4 noted this:

"everyone has the duty to get consent on projects…so the government can't give us a permit if its opposed by the communities… for example, without having buy-ins from the communities…we could risk the whole [operation]… Ajax [mine] never went through because the communities were opposed to it" (2020).

Allard and Curran (2021) provide evidence at a local scale that social license, Indigenous and community support is critical to ensuring mine operations can move forward. The above mentioned mine (Ajax) was not given consent by the Stk'emlupsemc te Secwepemc Nation to move forward within the culturally significant area known as Pipsell. Utilizing Secwepemc laws, traditions, customs, and land tenure systems the community assessed whether members would give their free, prior, and informed consent. This process resulted in the conclusion that the impacts to this cultural heritage area was simply viewed as unacceptable and likely irreversible (Allard and Curran 2021).

The idea of conducting this engagement is in part to ease any concerns of the local community at hand and in this case the Indigenous community to allow the mine operations to continue with business. Therefore, enhancing Indigenous relationships is partially guided as a business wise decision in order to maintain a social license to operate and reduce business risk, which can put limits on positive engagement with Indigenous communities.

As the political climate ensured further pressure on industry to assume a higher level of social responsibility HVC responded, and they increased engagement towards Indigenous communities as a priority. Participant #4 noted that “[HVC] has had an end land use plan since the late 90s but did not do any First Nations consultation on that plan” (2020). In 2015 HVC updated their end land use plan to incorporate Indigenous interests (Collaborative Land Use Planning at Highland Valley Copper 2021). It was this update to the end land use plan that resulted in increased engagement between HVC and the Nlaka’pamux community and developed into approximately twenty-four meetings in the period of 18 months. This level of engagement was noted as the first of its kind held by HVC (Canadian Mining Journal 2021). Concern regarding the impacts of the mine from the community resulted in a concerned response from the community as Participant #1 explained that “there’s rarely a community workshop that stress isn’t expressed” (2020). In leading the workshops and outreach Participant #4 also explained her experience conducting this engagement:

“it was the first time, really, someone from Highland Valley [was] coming into the communities to talk to the community as a whole. And… talking about end mine use planning... may not be what they want to talk about at all! So, I get questions on everything, like tailings, and construction and water and everything and a lot of times it was questions I could not answer, or you know…hard…hard conversations” (2020).

This quote speaks to a level of commitment from HVC to engage with the community in a manner that derived value as Participant #4 expressed that:

“when you stop and listened and acknowledge the impacts that the mine has had to people... that was when we started to be able to build relationships with the community members and just like listen to what they say, and like really try to develop this plan to…know that their concerns have been heard, and so that was really a huge learning experience for me” (2020).

This expression towards listening and continuing to improve engagement is a step forward to produce relationships built on specific plans and appropriate objectives.

It was two particular workshops held in December of 2017, totaling 5.5 hours where HVC had committed to seeking input from community members. Objectives of this meeting focused on the end land use planning of the mine with respect to biosolids application and fire in reclamation that resulted in the prescribed burning project (Appendix B, Figure B.1). A large sentiment that was expressed by Nlaka'pamux participants during these workshops and meetings was the desire to reintroduce prescribed burning into the management of land at HVC which is what spearheaded the implementation of the prescribed burning project. Participant #1 noted that "prescribed burning is always something that is talked about in workshops, it's kind of like water, it's an issue that people talk about how burning isn't incorporated anymore and their traditional ways of managing the landscape are no longer allowed to be implemented" (2020). It was this expressed sentiment by the Nlaka'pamux and acknowledgment by Participant #4 of the "significance of fire scientifically in ecosystems and importance to show that [Nlaka'pamux] knowledge was valued" (2020) that resulted in a formal prescribed burning project being implemented at HVC in 2019.

There was certainly a significant shift to increase Indigenous engagement into mine operations. Industry / Indigenous relationships have been transformed over time and this relationship is within its infancy in some capacities. Some critical questions to consider enhancing the industry / Indigenous relationship should determine if the integration of Indigenous knowledge is enough to constitute an acceptable level of engagement? I discuss additional factors that could constrain or enhance industry / Indigenous relationships.

PRESCRIBED FIRE PROJECT PARTNERSHIP CONSTRAINTS AND LMITATIONS

A project partnership considers decision-making, methodology, and project implementation. Additional considerations must be taken into account when working with Indigenous communities such as the duty to ensure Indigenous knowledges and peoples are not exploited (Kovach 2009). Ensuring these communities are not exploited typically involves in depth engagements with Indigenous communities and partners that draw upon research methodology that are in line with Indigenous values, while seeking ways to give back in a purposeful, helpful, and relevant manner (Kovach 2009). With these considerations in mind, I examined how the prescribed fire project between the Nlaka'pamux community and HVC was implemented and suggest ways in which this relationship could be further enhanced, noting that my interpretation is limited because I was unable to interview Indigenous participants.

An important sentiment that centers the argument around constraining the industry / Indigenous relationship for this project was noted by Participant #4:

"I get a sense … that [Indigenous] communities do not want us to just…send them things to review. They…want to be more part of the process and part of the decision making…" (2020).

In this case it is interesting that this sentiment was expressed by Participant #4 as this represents an acknowledgment that Indigenous communities are looking to be integrated at a level beyond document review. Engaging with the community at this level presents a positive approach to potentially enhancing the industry / Indigenous relationship by bonding with the community, and the fact that many HVC workshops involving the Indigenous community suggests that HVC is going beyond the level of document review by the Indigenous community. However, there were missed opportunities to engage further with the community.

Through the course of approximately sixteen end land use planning and engagement workshops with various Indigenous communities it was apparent that fire was a significant component that the communities wanted to address. This interest resulted in a follow-up three-hour workshop event as noted by Participant #2. During the three-hour workshop, Participant #4 explained that the level of Nlaka'pamux involvement included gathering traditional information by focusing on aspects of the "purpose…and timing of burning" (2020). When prompted about the role that the Nlaka'pamux community played within this project outside of providing the traditional knowledge of prescribed burning, all interview respondents expressed a similar sentiment. Ultimately, all respondents alluded to the fact that the role of the Nlaka'pamux in the prescribed fire project was mostly technical through speaking about the aspects and timing of burning and entailed a final review of a study design that was created by the consulting company. Additionally, Participant #2 explained that an "[Indigenous] fire crew from Lytton [was hired] to help conduct the burn, but beyond that I don't think there was any other participation" (2020).

This level of involvement and technical guidance by the community is paving the way forward towards creating industry / Indigenous engagements that work toward mutual goals. HVC showed commitment to listen to and integrate the community beyond document revision through this act, but this workshop event still presented missed opportunities to integrate Indigenous knowledge and expertise to a greater extent. Participant #1 explained that “people expressed the desire to carry out ceremonies before the burn to kind of make it something more meaningful and…involving more community members where more people would come up to watch… and that didn’t really happen… and then I think there were also hopes that didn’t just follow up of the project that there would be more participation… but yeah I guess industry priorities go in different direction” (2020).

As Participant #1 assumed a significant role in conducting these workshops, this expressed sentiment in the process acknowledges a missed opportunity.

A large disconnect was also noted between the desire to conduct engagement and the capacity to follow through at HVC. Both Participant #1 and Participant #2 presented plans of doing various community engagement programs with the Indigenous communities to increase engagement on the prescribed fire project. However, Participant #2 explained that a “budget reality check” (2020) from HVC quickly halted these desires and speculated that one reason this budget check may have occurred could be because “part of [the level of Indigenous involvement] is dependent on how much money is flowing through HVC, and what they can fund that isn’t a permit obligation” (2020). Participant #2 also expressed the notion that “community engagement [in 2020] was supposed to be happening…and then copper [prices] [decreased] due to COVID…” (2020). Community engagement activities with Indigenous communities across all sectors were limited in 2020 as COVID-19 limited contact to reduce virus exposure. The perceptions presented here by the consultant should be verified through HVC to determine the cause of budget shortfalls as consulting agencies like any business succeed by offering services that sometimes can go beyond the scope of a project to increase their revenues.

These expressions by both participants indicate the potential role that resource allocation could play to constrain community engagement at HVC and ultimately the relationships with the Nlaka’pamux. Bernauer and Slowey (2020) argue that the profitability of operations often constrain environmental and community values. This study demonstrates the importance of co-developing objectives when traditional ecological knowledge from the community is involved.

OPPROTUNITIES TO IMPROVE ENGAGEMENT AND RECCOMENDATIONS

As extractive industries will continue to operate within the province of B.C., relationships between industry and Indigenous communities will necessarily continue to evolve. These relationships are establishing collaborative approaches with common and clearly defined goals that are navigated outside of the boundaries of government mandates and instead focus on aspects of wellbeing to foster relationships where mutual benefits are priorities. This helps to evaluate whether or not community concerns have been addressed and creates a sense of accountability. Engagement could be improved by creating a closer bond with the community and conducting engagement that revolves around a larger consideration and enactment of their needs while considering Indigenous Methodologies to co-develop projects with sensitivity to community-based concerns. Additionally, community engagement sessions in the context of collaborative projects would not be limited to a finite number of events but ongoing and on an as needed basis to ensure both parties are involved at all stages of the project and come to a final agreement before enactment. As industries move at a fast pace and aim to meet deadlines and manage all aspects within their control, industry will need to recalibrate in order to engage Indigenous communities in a way that operates to further engage and develop respectful dialogue and relationships. As noted previously, my interpretations are limited because I was unable to interview Indigenous community members.

CONCLUSION

Many Indigenous communities continue to battle with issues of governance over ancestral lands, downstream health effects from various industries, and continually need to fight for maintaining a role in managing their lands in the face of industry (O’Faircheallaigh and Corbett 2005, Horowitz et al. 2018). Not all Indigenous communities are opposed to resource extraction and remain unheard partners in all instances where industry / Indigenous relationships are formed (Bernauer and Slowey 2020). A central theme of all interviews noted the importance of conducting Indigenous community engagement and assumed a role that appeared to advocate for it in one way or another. Even in the practice of my semi-structured interviews there was a lack of Indigenous engagement, thereby limiting my interpretations and my conclusions. Nevertheless, I detected a disconnect in the styles and patterns of communication on behalf of the mine from the consulting company to the Indigenous community, and the capacity for the Indigenous community to get involved in these matters may also play a significant role in constraining the industry / Indigenous relationship. It appears this relationship is partially managed on a basis of mitigating business risk in addition to being susceptible to market influences to commodity prices. Additionally, a missed opportunity by HVC was to act upon the sentiment expressed by the Indigenous community that indicated a desire to be involved in a significant socio-cultural ceremony for this project. These factors suggest a continued relationship out of necessity, and a disconnect between each party in the roles being assumed throughout the project. The natural resource and industry sectors need to recognize the potential they hold to aid in positive social developments beyond what has currently been completed. Positive momentum is occurring with respect to conducting this engagement and opening a line of dialogue to address ways to enhance these important relationships. Ultimately, the integration of Indigenous knowledge through technical participation is likely not enough to constitute as an acceptable level of engagement. The long-term focus with creating industry / Indigenous relationships should focus on building capacity to co-create research initiatives that meet goals of both parties and aims to privilege Indigenous knowledge not only for its technical aspect. This analysis represents a non-Indigenous, and limited perspective from the consideration and context of this particular project. Future research should focus on continuing the relationship with the Nlaka’pamux and integrate the Indigenous perspective on this matter to fully consider the implications of this relationship. Future engagements should further consider and enhance the use of Indigenous Methodologies and epistemologies to help develop these relationships and collaborate on projects that provide mutual benefit to both parties. Finally, future studies on perception of Indigenous / Industry relationships needs to include direct Indigenous participation that was desired to be conducted in this study but due to limited timeline was unable to be completed.

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Chapter 3 : UTILIZING PRESCRIBED BURNING AS A TOOL TO ENHANCE NATIVE GRASSLAND RECOVERY ON A TWENTY-FIVE-YEAR-OLD RECLAIMED MINE-TAILINGS FACILITY DOMINATED BY NON-DESIREABLE VEGETATION

ABSTRACT

Prescribed burning was introduced as a tool to enhance biodiversity within a twenty-five-year-old historically reclaimed grassland located at Highland Valley Copper mine in British Columbia, Canada. The grassland is represented by a current state of ‘arrested succession’ characterized by a low diversity of non-desirable grass species such as *Elymus trachycaulus, Elymus lanceolatus, Thinopyrum intermedium* and *Bromus inermis.* As mines have increasingly noted the significance of biodiversity and native species to reclamation, goals set out by the mine and local Indigenous community are directed in reclaiming this ecosystem to a grassland state dominated by largely more native species. To determine the effects of prescribed burning, three experimental treatments (Burn, Burn + seeded + tree planted, and control), replicated three times per treatment, were applied to 20 x 20-meter plots. Sowing of seed comprised of native species and tree seedling planting that occurred one day after burning. Prescribed burning resulted in a significant increase of species richness and diversity within the plots that were burned without any other amendment. Community level divergence was significantly increased across all treatments due to burning. The role of litter and the highly productive nature of the previously established plant community was found to play a significant role in arresting succession for the site and limiting establishment of newly sown and planted species. I confirmed that a significant negative relationship exists between litter and diversity. These results suggest prescribed burning

alone or when paired with seeding in this instance is not enough to allow new entrants into the plant community. The established plant community remains to be a highly competitive, and productive even after burning, which limits the succession of new species.

INTRODUCTION

Mining has taken place on a massive global scale for several centuries. The life of a mine is limited, and damages that occur to the environment through extraction must be reclaimed or restored after mine closure (Venkateswarlu et al. 2016). It is not uncommon knowledge that mining operations are one of the major contributors to severe degradation of the environment (Sheoran et al. 2010), while leaving behind an amount of waste equivalent to the magnitude of 1:1, ore extracted to waste, and often orders more due to inefficiencies (Lottermoser 2011, Adiansyah et al. 2015). Mine tailings are one waste product of processing and grinding rock material in order to extract the desired metal. Although variable chemical or physical processes are implemented to remove each desired commodity (Sample and Barlow 2013, Kossoff et al. 2014), mine tailings are universal with respect to being low in organic matter and essential plant nutrients, and are often fine textured sandy material (Sample and Barlow 2013, Kossoff et al. 2014). Mine tailings pose a significant risk as they often contain potentially hazardous contaminants and trace heavy metals. As such, it is a high priority for mines to manage their tailings from entering groundwaters, rivers and lakes, while also reducing eolian dispersion. Management techniques vary from riverine disposal, submarine disposal, wetland retention, backfilling, and dry stacking storage (Lottermoser 2011). In semi-arid and arid environments, dry stacking storage is a common technique and desirable for both economical and reclamation purposes as reclamation can occur progressively.

Restoration or reclamation following the mining process is both complex and challenging due to biotic and abiotic factors that limit ecosystem productivity (Turner et al. 2006, Gasch et al. 2014). Many characteristics of mine wastes often provide unfavorable conditions to successful vegetation establishment, notably the levels of residual heavy metals, low nutrient status, poor physical structure of soils, and extreme pH values (Tordoff et al. 2000, Sample and Barlow 2013). In semi-arid and arid environments this challenge is further exacerbated by lack of precipitation which exerts a primary control of plant productivity and composition (Bates et al. 2006). As one of the first steps in reclamation or restoration of these lands is typically revegetation, the combination, and interactive effects of unfavorable substrate, paired with low annual precipitation can compound the challenges with restoration in semi-arid mine lands and poses a unique challenge.

Highland Valley Copper Mine (HVC), located within British Columbia (B.C.), Canada, along with many other mines have created grasslands dominated by largely non-native, long-lived, sod-forming, highly productive, agronomic and forage crops in order to overcome the challenges stated above (Brothers 1990, Swab et al. 2017). In the 1970's, a vast majority of reclaimed mine landscapes utilized these types of grasslands to reclaim disturbed mine lands and provide a simple vegetative cover. The focus on simply establishing vegetative cover fails however, to address a long term succession plan for the community and consider the needs of biodiversity in ecosystem function (Mendez and Maier 2008). Many of these ecosystems have converged towards a monoculture or low diversity grassland state with aggressive competition resulting from the hearty, forage species that have ultimately been shown to 'arrest succession' (Swab et al. 2017). This 'arrested succession' can be partially attributed to highly productive communities resulting in significant biomass and litter accumulation that reduces species richness and biodiversity through altering plant community dynamics (Foster and Gross 1998, Collins and Calabrese 2012).

In these communities, litter accumulation if not managed can result in generational effects in plant community organization by favoring previously established, or tall lived species (Peco et al. 2012, Loydi et al. 2013). This generational effect can be attributed to accumulation of litter in excess amounts (~ 500 g m^{-2}) that act as a mechanical barrier to limit recruitment and seedling emergence by changing the physical conditions that are needed for growth by restricting light quantity, and changing soil moisture (Facelli and Pickett 1991, Loydi et al. 2013). Unfortunately, many approaches to mine reclamation still use non-native or exotic species that will provide a cover crop as fast as possible, resulting in a high accumulation of biomass and litter, ultimately restricting the plant community. When reclaiming ecosystems or disturbed areas at this scale, incorporating specific, well adapted native plants into reclamation can increase the value of the ecosystem by allowing room for other plants, and potentially improve soil conditions more quickly than non-native plants through fostering biodiversity (Swab et al. 2017). The new ecological problem lies within changing the trajectory of previously reclaimed plant communities dominated by non-desirable, hearty forage species to biodiverse, native plant communities which we know to often be impeded by the competitive advantages of the established community (Yahdjian et al. 2017).

This field trial represents a partnership between HVC and the Nlaka'pamux peoples where the combination of Indigenous knowledge of prescribed burning was paired with contemporary ecological disturbance theory and western methods to increase diversity within the tailings storage facility.

Fire can play an integral role in ecosystems by acting as a mechanism to sustain structure and diversity in plant communities (Moritz et al. 2014). The ecology of fire works primarily by affecting and ultimately increasing the availability of resources such as light, while aiding in nutrient cycling and increased nitrogen availability (Swanson et al. 2011). Additionally, fire acts as a disturbance to remove accumulated plant litter which can favor the establishment of new species through various abiotic and biotic ecosystem changes such as: increased solar radiation, and allowing a period of reduced competition (Brockway et al. 2002, Scheintaub et al. 2009). Prescribed fire can ultimately modify relationships among species and change dominance in the plant community due to species specific responses (Ghermandi et al. 2004, Collins and Calabrese 2012, Augustine et al. 2014).

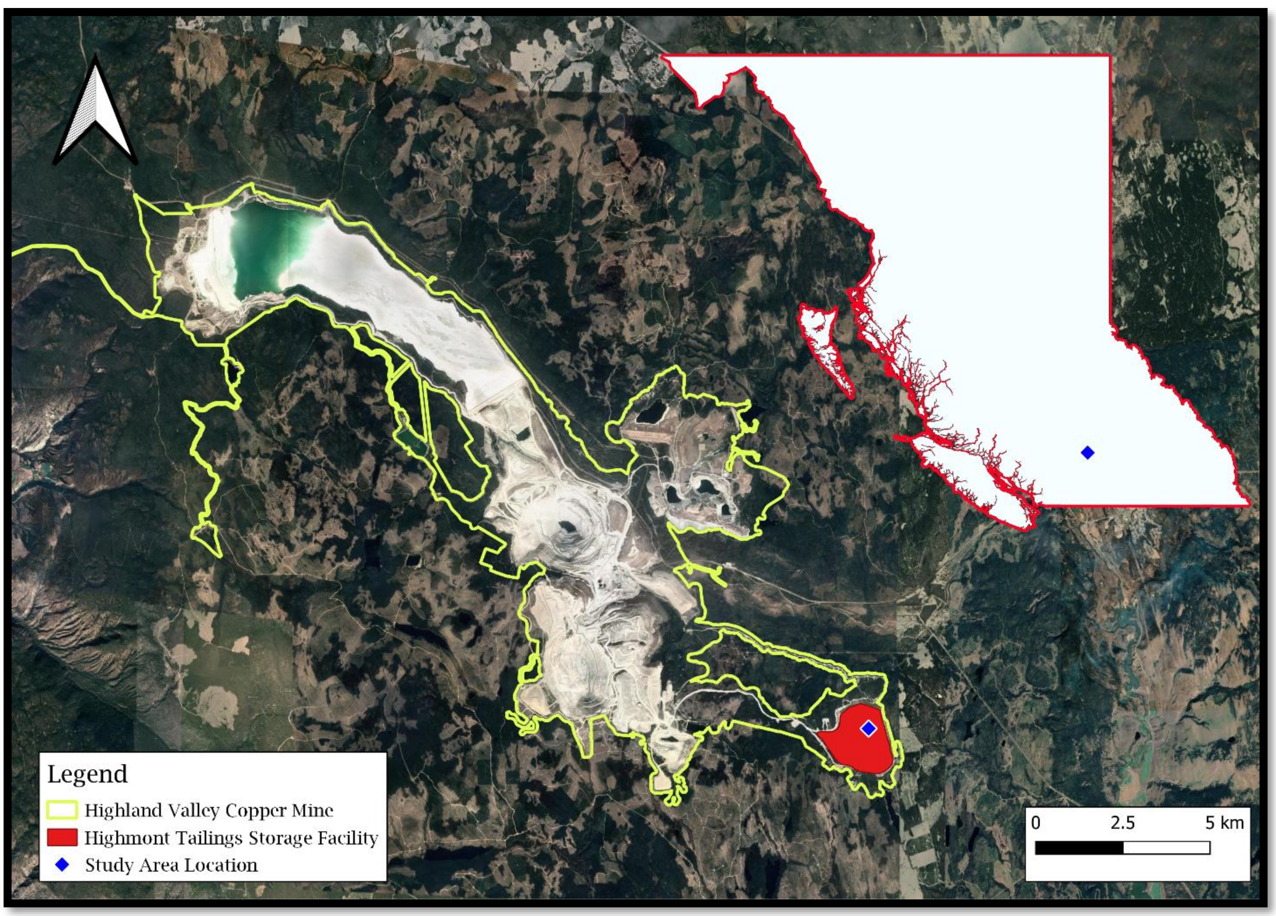
Specifically, the context in which prescribed burning has been used as a mechanism to aid in the reclamation of disturbed communities on mine lands represents a significant knowledge gap within existing scientific literature. The purpose of this research was to determine the relative effect that prescribed burning plays on a twenty-five-year-old historically reclaimed plant community. Specifically, I examined the ability of prescribed burning as an ecosystem reclamation tool to shift the ecosystem trajectory away from a non-desirable plant community towards a native plant community resulting in increased biodiversity.

METHODS

Study Site

In May of 2019, a total of twelve prescribed fires were conducted at Highland Valley Copper (HVC; UTM Z10;638846E, 5594478N, Figure 3.1) within the southern interior of British Columbia (B.C.), Canada. The history of the Historic Highmont Tailings storage facility represents twenty-five years of reclamation work. Notable reclamation efforts include a series of seeding trials in 2008 (35kg/ha) with hearty, non-desirable species, and the application of biosolids, treated municipal sewage, to assist establishment of a vegetative cover to the non-capped tailings material (Figure 3.2B). Biosolids were provided by Metro Vancouver and applied in 2006 (200dt/ha).

The study site is located at an approximate elevation of 1500 m within the Montane Spruce Msxk2 biogeoclimatic zone (Government of British Columbia Ministry of Forests 1991). The Montane Spruce zone is characterized by cold winters and moderately short, warm summers.



The mean annual temperature is 3-4.5 °C and mean annual precipitation ranges from 380 – 900 mm (BC Climate Explorer 2021).

The prescribed burns were conducted at the Highmont Tailings facility (UTM Z10; 647608E; 5588930N), a twenty-five-year-old, historic tailings storage facility that has been reclaimed to a grassland dominated primarily by agronomic and non-desirable C_3 grass species such as: *Elymus trachycaulus, Agropyron spp., Elymus lanceolatus, Thinopyrum intermedium & Bromus inermis*. Additional species include a very low abundance of C_3 non-leguminous forbs (*Achillea millefolium & Sisymbrium altissimum*). These forb species, even though considered native, are common to reclamation projects due to their positive response to poorly developed, well drained soils and overall heartiness.

Figure 3.1. Field study site located at Highmont Tailings, within Highland Valley Copper Mine, British Columbia, Canada.

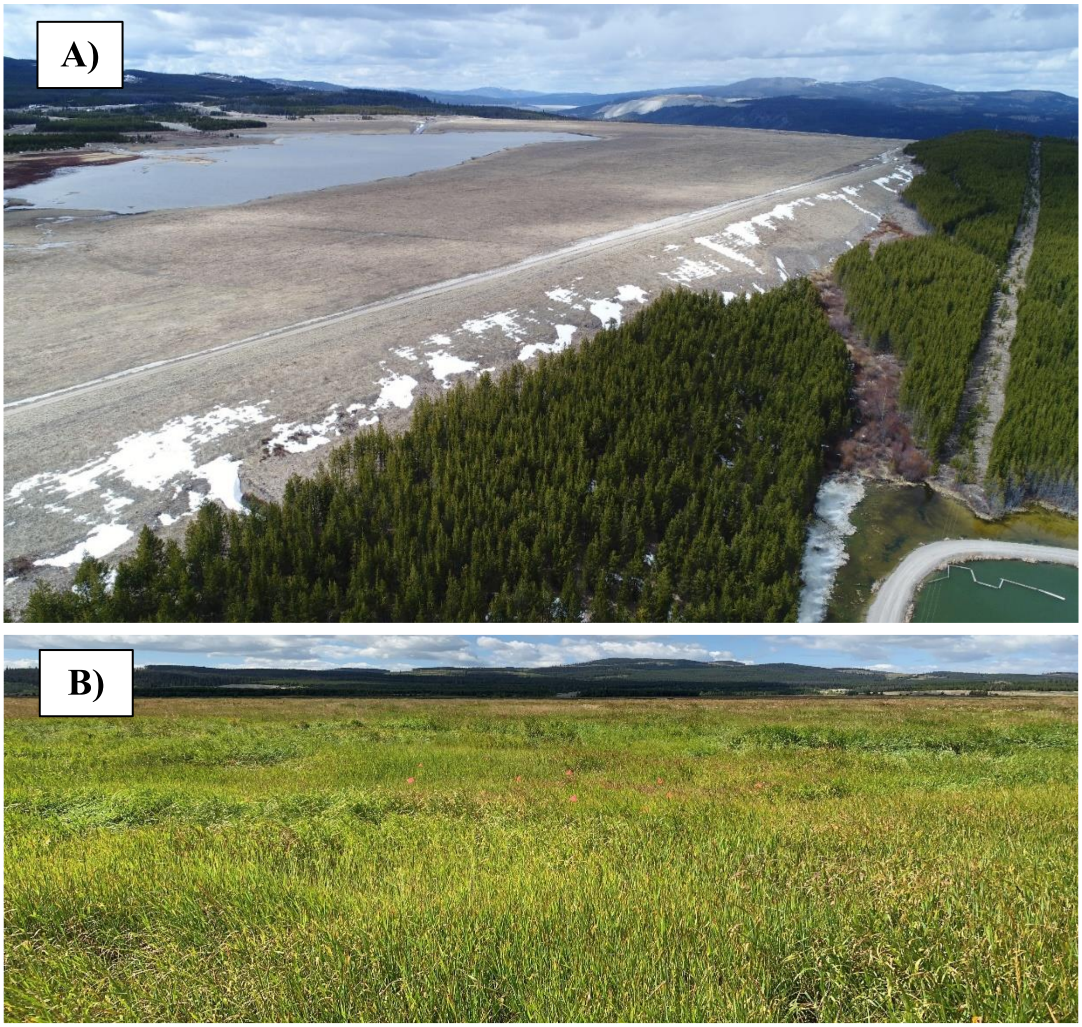


Figure 3.2. A) Aerial photo of the Historic Highmont Tailings dry stack storage at Highland Valley Copper, April 2019. B) Current vegetative cover during peak growing season at Highmont Tailings Storage Facility, August 2019.

Experimental Design

The experiment was established, and treatments were applied in late May of 2019. A total of twelve plots (20 x 20 m) were arranged in a complete randomized block design spaced a meter apart on each side. A single fire disturbance was applied to each plot which received a combination of amendments to distinguish four treatment types. Amendments included application of woody debris (W), seeding with native forb, legume, and grass species (S) (Table 3-1.), and tree planting (P). Resulting in a total of four treatments replicated three times per treatment: Burn (W+S+P), Burn (S+P), Burn (B), and control (no amendments or burning) (Figure 3.3). Outside consultants operationally added the treatment 'Burn (W+S+P)' but for the purposes of this study, this treatment was omitted from the analysis as the application of woody debris did not meet the scope or objectives of our study. Additionally, due to operational challenges in getting on site, preburn vegetation and biomass data was unable to be collected prior to burning on certain plots.

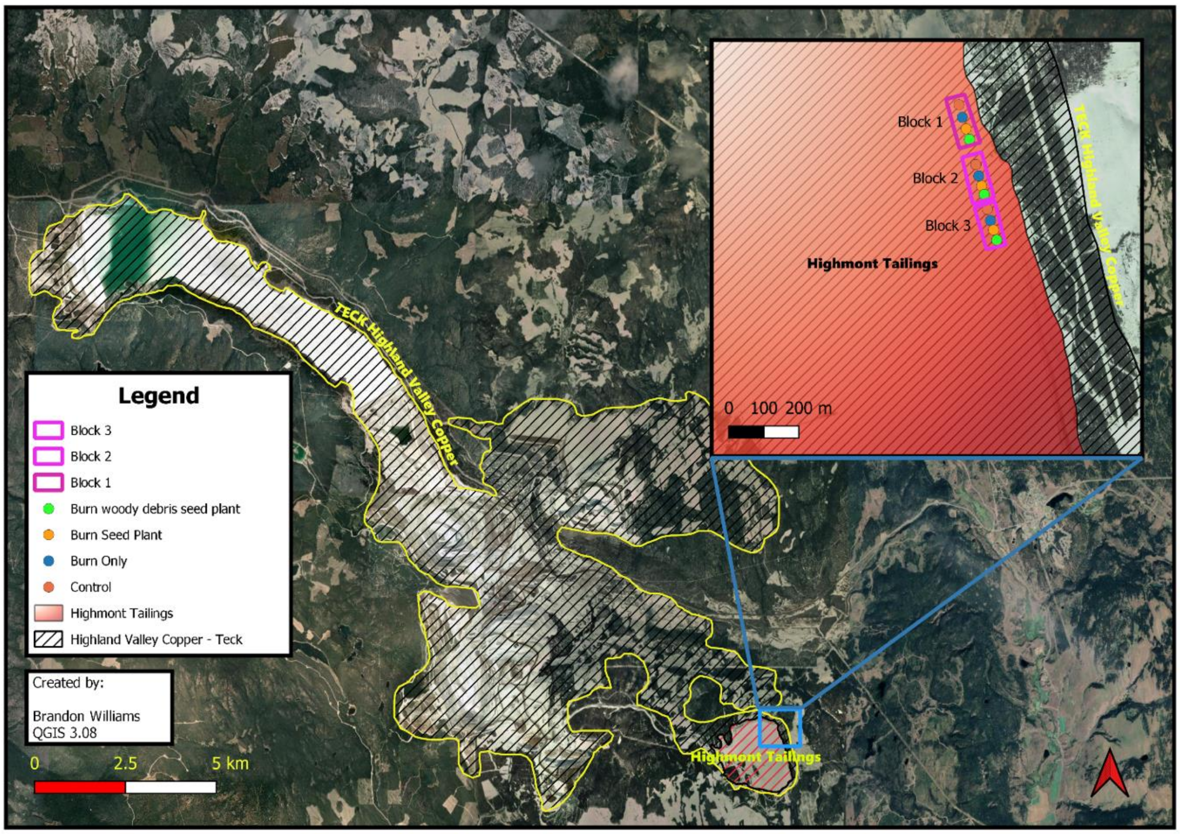


Figure 3.3. Overview of experimental design located at the Historic Highmont Tailings facility at Highland Valley Copper.

Amendments

Native grass, forb, and legume seeding occurred after the prescribed burn at a density of 20 kg/ha using a broadcast seeding method (Table 3-1). All seeds were acquired from a commercial source, see Appendix C for germination test results. Aspen (*Populus tremuloides)* and lodgepole pine (*Pinus contorta)* were planted post burn at a density of 5000 stems per hectare (sph). Plant and tree species were selected based on environmental data that would suit the selected species.

#	Common Name	Scientific Name	Functional Group	Succession
1	Western Yarrow	*Achillea millefolium*	Native Forb	Early
2	Arctic Lupine	*Lupinus arcticus*	Native Legume	Early
3	Rocky Mountain Fescue	*Festuca saximontana*	Native Grass	Early
4	Idaho Fescue	*Festuca idahoensis*	Native Grass	Late
5	Junegrass	*Koeleria macrantha*	Native Grass	Early-Mid
6	Sandbergs Bluegrass	*Poa secunda*	Native Grass	Early
7	Bluebunch Wheatgrass	*Pseudoroegneria spicata*	Native Grass	Late

Table 3-1. List of native plant species included in the operational seed mix, indicating successional status and plant functional group.

Fire Treatment

An Indigenous fire crew was contracted to carry out the prescribed burning. A single point fire on each plot was initially attempted to allow the fire to carry naturally with the wind. Due to the time of year, high elevation, high ground moisture levels, and greenness of vegetation at the time of burning, the fire did not carry naturally. To conduct the prescribed burn, the fire crew walked the entirety of the plots with a Tiger Torch™ (Model No. 95-B) and removed all above ground biomass and litter (Figure 3.4).

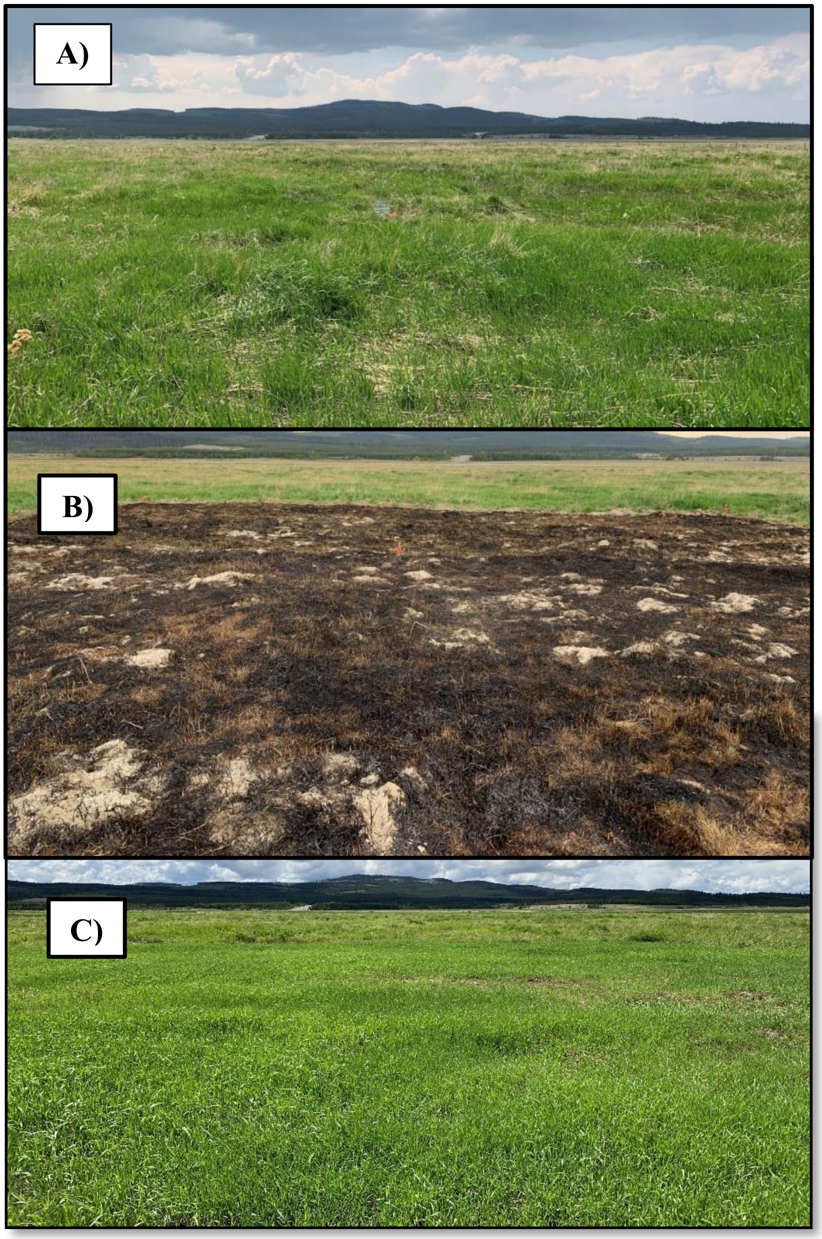


Figure 3.4. A) Plant community present at Highland Valley Copper, Highmont Tailings site prior to burning. B) Post prescribed burning with a propane Tiger Torch™ (Model No. 95-B). C) Plant community one month after burning.

Flame temperature was recorded within each plot using self-constructed pyrometers utilizing Omegalaq™ temperature sensitive paints ranging from 107 °C to 510 °C. The temperature sensitive paints were applied at gradations of approximately 30 °C and painted on pieces of tin that were placed at the center of each plot (Figure 3.5). Due to lack of ignition on site and thus lack of natural fire movement, the temperature pyrometers were ineffective and did not capture data reliable for estimating flame temperature.

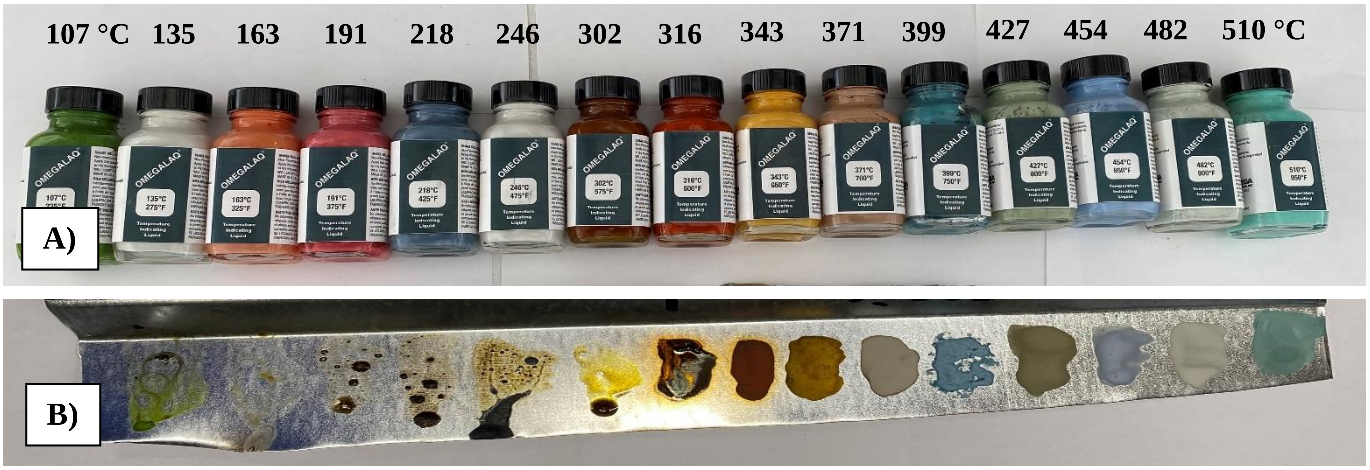


Figure 3.5. Omegalaq™ temperature sensitive paints applied at gradations of approximately 30 °C used to quantify fire temperature. A) Omegalaq™ paints from lowest to highest temperature. B) Example of paint change resulting from heat exposure in a lab setting.

Vegetation Assessment & Harvesting

Vegetation measurements were collected within each plot prior to burning and prior to final harvest (15 months postburn), using absolute canopy cover estimation within a 1 m by 1 m quadrat. Additionally, above-ground biomass and litter were collected within a smaller, 0.5 m by 0.5 m sub-quadrat to quantify the above ground net primary productivity (ANPP). A total of eight quadrats were analyzed per plot, with biomass and litter only being harvested in four of the eight quadrats. Each plot was selected randomly prior to arriving at the field by use of a random direction and position from the plot centroid. To better understand plant community dynamics, richness was calculated as the number of species present within each quadrat, evenness and dominance were calculated respectively using the Shannon-Weiner index which accounts for richness and evenness, and the Simpson index which is sensitive to dominance (Morris et al. 2014).

Postburn sampling occurred during peak growing season during early August to allow for maximum biomass growth. Plant biomass samples were harvested as close to the soil surface as possible and separated by species. Litter was collected after ANPP was collected by scraping dead material off the soil surface. All plants were oven-dried for approximately 48h at 65 °C and weighed.

Due to mine site access issues, preburn data is missing for treatment 'Burn (S+P)' as the mining partner had begun completing the prescribed burning prior to our arrival.

Soil Sampling, Elemental Analysis & pH

A total of nine random soil samples were extracted at varying time intervals (preburn, immediate post-burn, six months post-burn and fifteen months post-burn). Soil samples were extracted using a stainless-steel soil sampling probe with a core diameter of 2 cm. Only the top 15 cm of the soil profile was extracted for analysis. Soils were analyzed at TRU for total nitrogen (TN), total carbon (TC), C:N ratio, and pH using a Thermo Scientific Flash*Smart*™ Elemental Analyzer and a Fisherbrand™ accumet™ AB150 benchtop pH meter.

Soil preparation for elemental analysis included air drying within a Yamato™ drying oven (model DKN812) for 48 hours at 65°C to remove any moisture. After drying, approximately 10-15mg of soil was weighed and placed into small tin capsules for placement into the elemental analyzer auto-sampling wheel. A total of three technical replicates were taken from each soil sample to ensure quality of analysis. In addition to examining each technical replicate against one another, Organic Analytical Standards (OAS) of known nitrogen and carbon values provided by Thermo Scientific™ were analyzed to ensure accurate estimation of elemental analysis.

Soil pH was measured in an aqueous matrix using a 2:1 water to soil ratio (Carter and Gregorich 2007). Air-dried soil was mixed and shaken with deionized water for one minute and then placed in a centrifuge and run at 4000rpm for five minutes. A Fisherbrand™ accumet™ AB150 benchtop pH meter was then calibrated with a pH 4, 7, 10 solution and used for analysis.

Statistical Analysis

All statistical analyses and figures were produced using R for Statistical Computing (R Core Team 2021). In all cases, significance was defined by $p < 0.05$. Data were analyzed using mixed model of analysis of variance using the 'lmer' function from the package "lme4". For all analyses completed, the random effect was the plot from which the measurements were performed. Fixed effects for all models were extracted through running an analysis of variance (ANOVA) on the selected model. Post hoc analysis was done by completing pairwise comparisons and the p-values were adjusted with Benjamini-Hochberg (BH) corrections (Benjamini and Hochberg 1995).

All linear mixed effects models used were first checked to meet the assumptions of normally distributed residuals, and homogeneity of variance. Transformations of the data paired with non-parametric methods were used when data did not meet the above assumptions.

Plant cover data from each sampling quadrat was analyzed by examining Shannon-diversity and Simpson-diversity indices that were calculated using the 'vegan' package in R for statistical computing. Species richness was calculated as the number of unique species per quadrat. Shannon diversity, Simpson's index and species richness was analyzed comparatively between disturbance treatments and timing using linear mixed effect modeling.

A permutational multivariate analysis of variance (PERMANOVA) analyzing Bray-Curtis dissimilarity was used to assess community-level divergence between treatments and timing. This index is bound between zero and one, with zero indicating complete similarity in relative abundance of all species, while one indicates that no species are shared between the samples. The 'adonis' function in the 'vegan' package in R was used to complete this analysis. Species assemblages were normalized first using the Hellinger method. Bray-Curtis dissimilarity distances were then extracted in R to produce a boxplot to display dissimilarities between factors and examine post-hoc pairwise comparisons. To determine what features were driving change in the community I utilized random forest machine learning with the 'randomForest' package in R.

To examine the relationship between burning, litter biomass and alpha diversity, the relationship was plotted. Richness, Shannon-diversity, and Simpson-diversity were analyzed but only Shannon-Diversity was plotted for visual representation as all diversity metrics represented approximately the same relationship.

Aboveground net primary productivity (ANPP) and litter was collected fifteen-months-postburn and analyzed by treatment, and functional group against the control treatments using linear mixed effect modeling. ANPP that was analyzed by functional group did not meet the assumptions for normality in some cases so data transformation using square root was applied.

Soil data was analyzed using a Flash*Smart*™ Elemental Analyzer that returns total concentrations for various major elements. Total carbon, nitrogen, and carbon to nitrogen (C:N) ratio were analyzed comparatively between disturbance treatments, timing from pre disturbance to post disturbance using linear mixed effect modeling. Assumptions for running linear mixed effect models for each elemental concentration along with C:N ratio were validated, and no data transformations were needed.

RESULTS

Species Richness, Evenness and Diversity

Examining the effect of burn treatments on alpha diversity metrics resulted in significant effects within species richness and Shannon-diversity (Table 3-2.). Comparisons of burn treatments by post-hoc comparison resulted in significant differences between species richness ($F = 4.77$, p.adj = <0.01) and Shannon diversity ($F = 3.40$, p.adj = <0.05), within the ‘Burn’ treatment, indicating increased diversity fifteen months after treatments were applied (Figure 3.6). The significance of these results indicate that addition of other amendments (seeding + tree planting) did not aid in increasing diversity.

Table 3-2. ANOVA to determine the significance of burn treatment and timing effect on richness, Shannon-Diversity and Simpson-Index (1-D).

Model:	**Species Richness = Burn Treatment + Quadrat ID (Error)**				
Effect					
	Sum-of-squares	Mean squares	df	F-Value	p
Burn Treatment	21	10.50	2	4.77	<**0.01**
Model:	**Shannon-Diversity = Burn Treatment + Quadrat ID (Error)**				
Effect					
	Sum-of-squares	Mean squares	df	F-Value	p
Burn Treatment	1.33	0.66	2	3.40	<**0.05**
Model:	**Simpson-Diversity = Burn Treatment + Quadrat ID (Error)**				
Effect					
	Sum-of-squares	Mean squares	df	F-Value	p
Burn Treatment	0.27	0.13	2	2.32	0.10

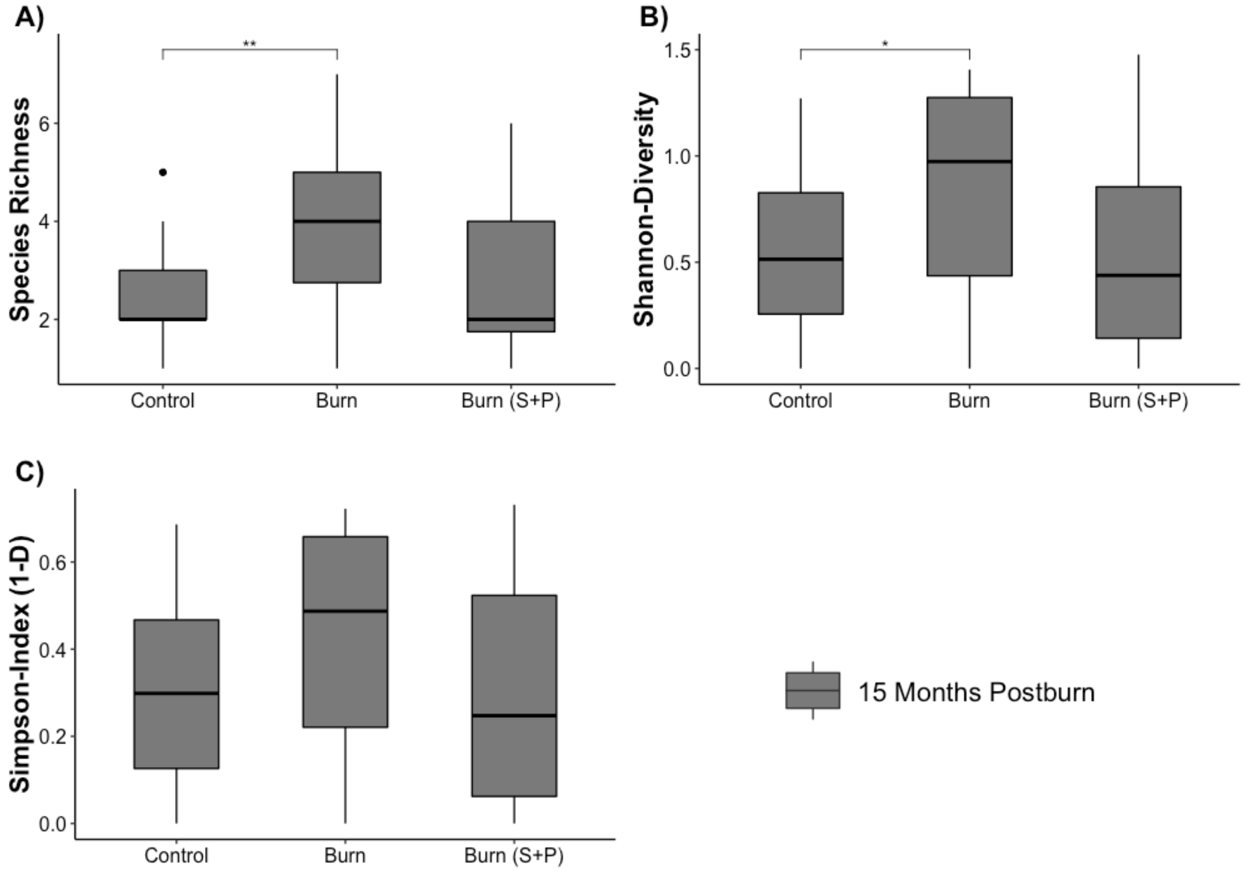


Figure 3.6. A) Species Richness, B) Shannon-Diversity, C) Simpson-Index (1-D) as an effect of burning treatments (n control = 24, n Burn = 24, n Burn(S+P) = 24). Pairwise comparisons were conducted within each group and were compared to the control and adjusted with BH corrections. '*' $p < 0.05$, '**' $p < 0.01$. Non-significant values were not plotted. Burn (S+P) treatment was seeded and planted with trees and Burn treatment was only burned.

Plant Community Analysis

The response of the plant community to fire treatment and timing was further investigated with a permutational multivariate analysis of variance which revealed that community structure based on Bray-Curtis dissimilarities was significantly different between plots ($p<0.001$, Table 3-3).

Generally, fire treatment and timing appear to have resulted in a significant shift in the community structure. Pairwise comparisons revealed that the 'Burn' treatment, along with 'Burn (S + P)' when compared to the control plots, resulted in significantly greater Bray-Curtis dissimilarity distance such that less species are shared between plots (p<0.001, Figure 3.7. , Table 3-3). Plant community response to timing based on Bray-Curtis dissimilarities was also found to be significant (p<0.001, Figure 3.7., Table 3-3).

Table 3-3. PERMANOVA testing community structure based on the effect of burn treatment (control, Burn, Burn (S+P)) and timing (preburn and 15-month postburn) for plots located on Highmont Tailings, HVC. NB perms: 999

Source of Variation	*df*	F	p
Burn Treatment	3	3.37	**0.001**
Timing	1	5.62	**0.001**
Burn Treatment*Timing	2	0.32	0.797
Residuals	122		
Total	128		

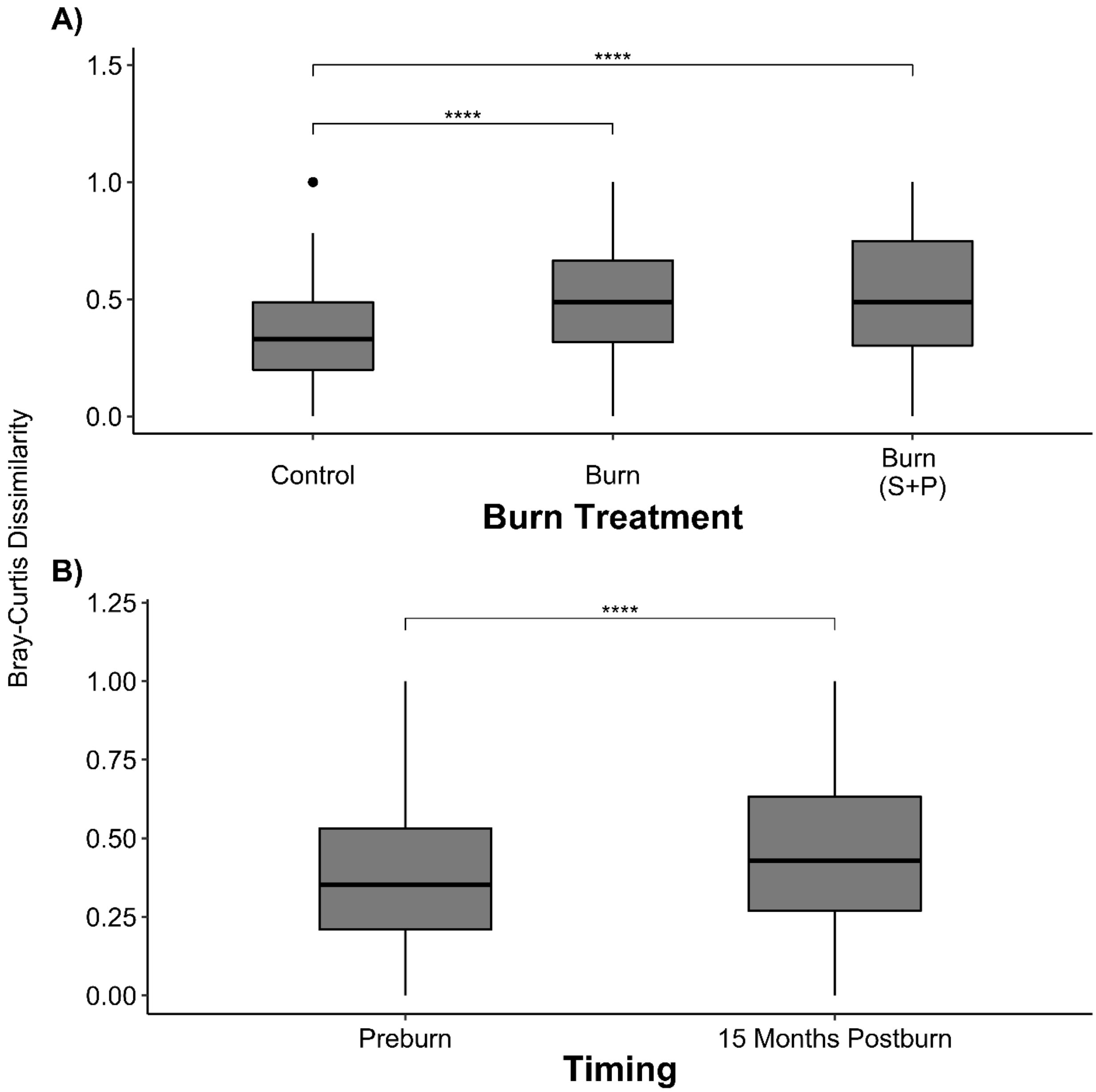


Figure 3.7. Extracted Bray-Curtis Dissimilarity distance plotted by A) Burn Treatment (fifteen months postburn) and B) Timing for field plots located on HVC, Highmont Tailings. Burn (S+P) treatment was seeded and planted with trees and Burn treatment was only burned. 15 Months Postburn pools all treatment plots excluding the control and Preburn pools all treatments.

Random Forest

Random forest (RF) modelling was completed to evaluate variable importance to determine what was driving the observed change across alpha and beta diversity measures in timing and treatment factors. I plotted variable importance as mean decrease Gini for the top four variables of importance (Figure 3.8).

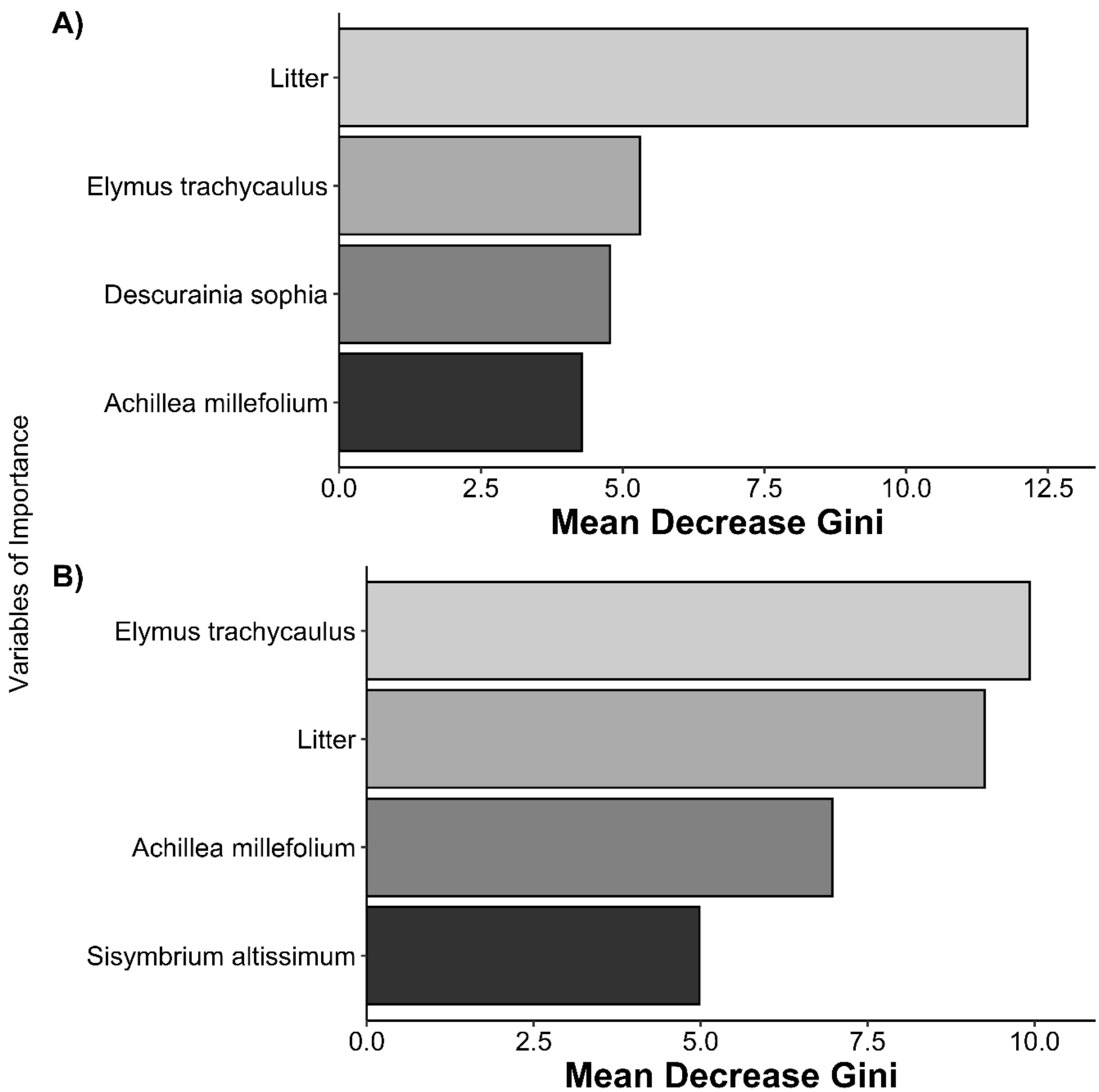


Figure 3.8. Random forest generated variables of importance driving beta diversity response due to factors: A) Timing and B) Burn Treatment for field plots located at HVC, Highmont Tailings.

Each variable of importance was then analyzed for significance using linear mixed effect modelling among treatment and timing factors to validate variable importance (Figure 3.9). Only variables of significance within modelling were included in figures.

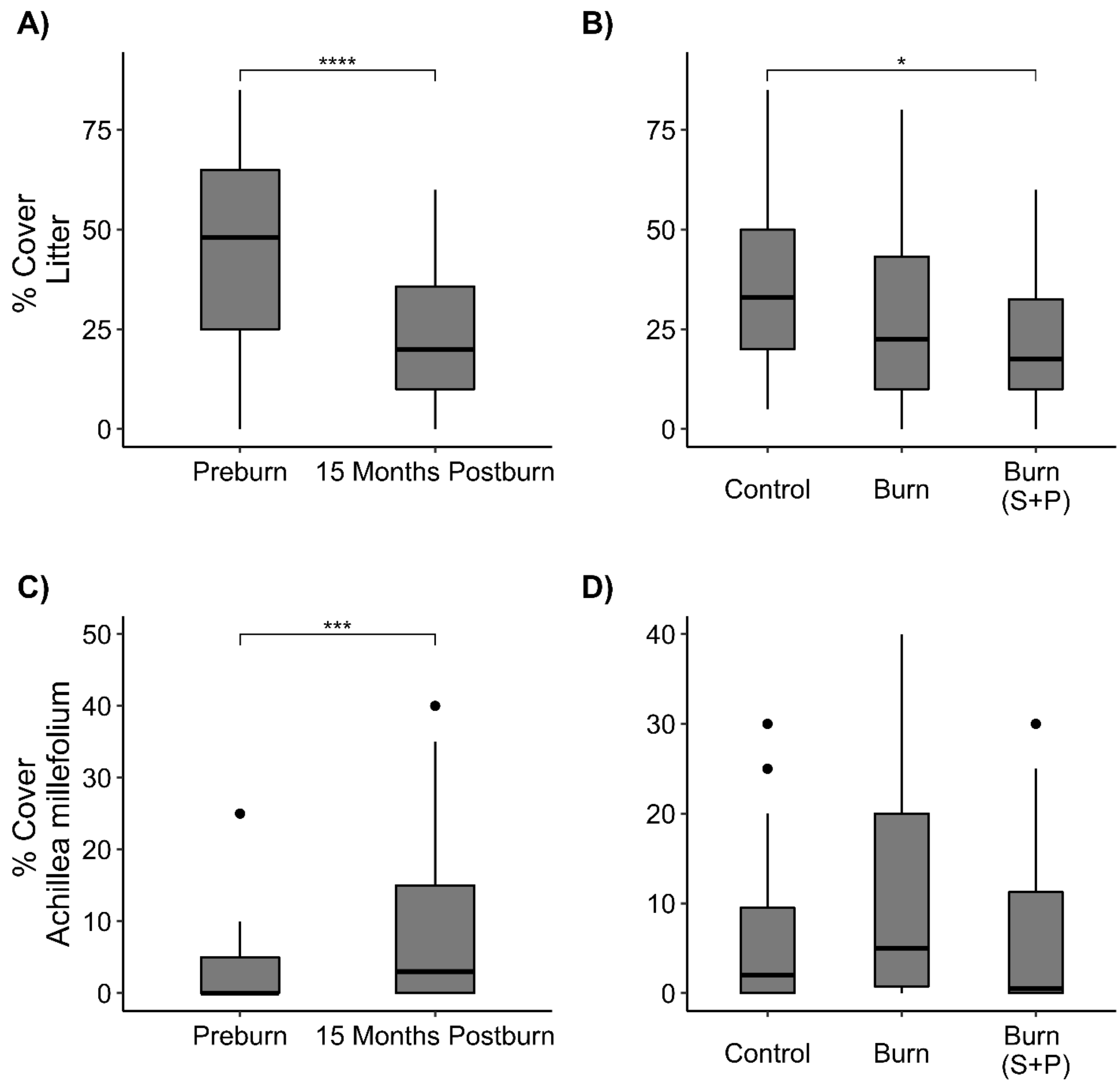


Figure 3.9. Percent cover of litter across factors of A) Timing (n preburn = 33, n fifteen months postburn = 95) and B) Burn Treatment (n control = 42, n Burn = 36, n Burn(S+P) = 24), and percent cover of *Achillea millefolium* across factors of C) Timing and D) Burn Treatment. Pairwise comparisons for Burn Treatment factor were compared to a base mean from ‘control’

and adjusted with BH corrections. ‘*’ $p < 0.05$, ‘**’ $p < 0.01$, ‘***’ $p < 0.001$, ‘****’ $p < 0.0001$. Burn (S+P) treatment was seeded and planted with trees and Burn treatment was only burned.

Significant differences in percent cover between preburn and fifteen months post burn were found with respect to both litter cover (Figure 3.9A., $F = 34.03$, $p < 0.0001$) and *Achillea millefolium* (Figure 3.9C., $F = 13.203$, $p = <0.001$). Total cover of litter decreased fifteen months after burning while total cover of *Achillea millefolium* increased indicating a positive trend toward forb response to fire. Response to ‘Burn treatment’ trends were less apparent such that only a significant difference was found with respect to cover of litter between control and ‘Burn (S+P)’ (Figure 3.9B), $F = 3.25$ p.adj = <0.05). Percent cover of *Achillea millefolium* approached significance but was not statistically significant given $\alpha = 0.05$ (Figure 3.9D), $F = 2.74$, $p = 0.07$).

Litter & Diversity Relationship

To examine the relationship between diversity and litter, linear regression was conducted examining Shannon-diversity, Simpsons Index, and species richness against litter biomass. There was a significant but weak negative relationship among all diversity measures against litter biomass (Shannon-Diversity = 0.96 – 0.005 x litter mass, Adjusted $R^2 = 0.12$ $p = 0.02$, Simpson-Index = 0.51 – 0.003 x litter mass, Adjusted $R^2 = 0.11$, $p = 0.03$, Species richness = 4.16 – 0.02 x litter mass, Adjusted $R^2 = 0.13$, $p = 0.02$). Only Shannon-Diversity was plotted for visual representation (Figure 3.10). This relationship reiterates the negative effect that litter appears to place on the plant community, as it appears to limit diversity.

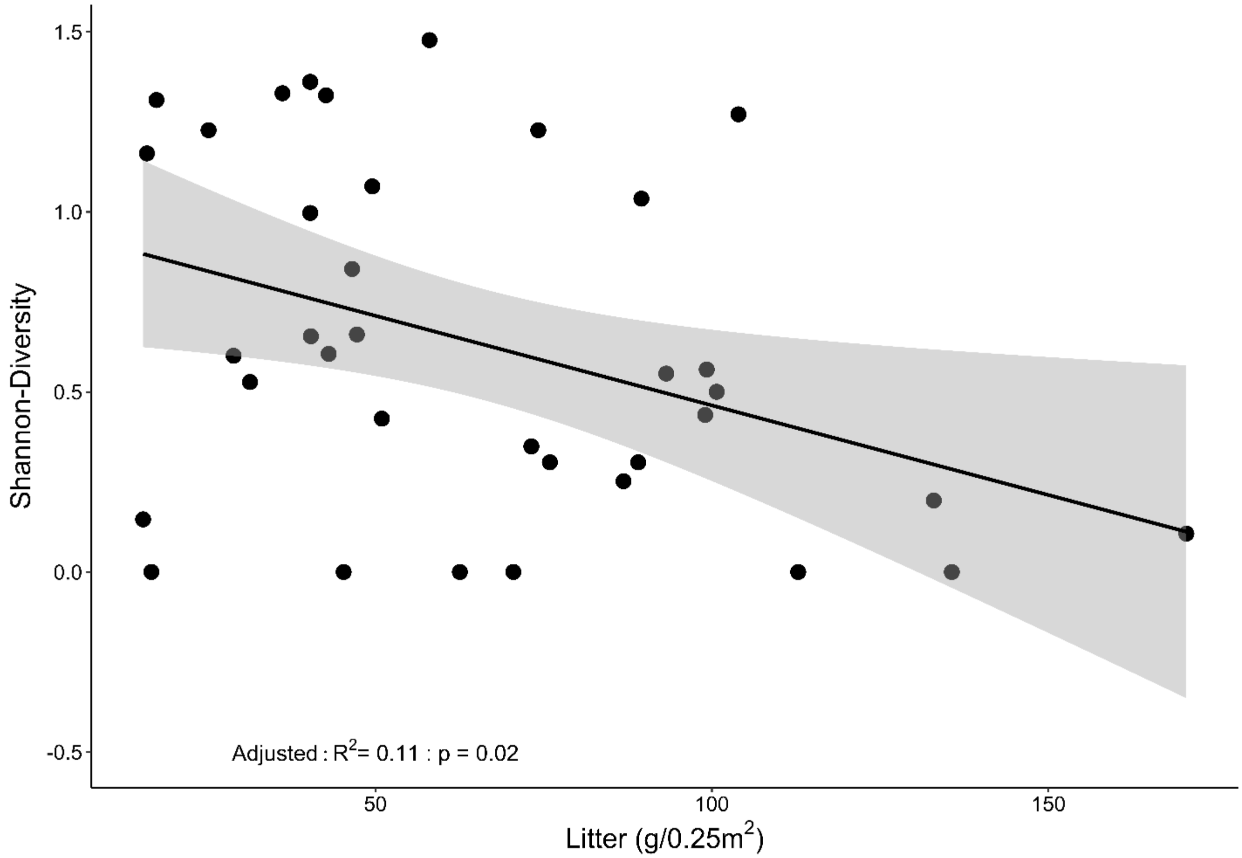


Figure 3.10. Relationship between Shannon-Diversity and litter mass fifteen months postburn. Shannon-Diversity = 0.96 – 0.005 x litter mass, Adjusted R^2 = 0.12 p = 0.02.

Disturbance, Productivity and Litter

Burn treatment did not result in any significant effects on ANPP (F = 1.09, p > 0.05, Table 3-4., Figure 3.11A.) suggesting that burning did not result in any significant change of productivity to the plant community. However, burn treatment resulted in significantly reduced litter (F = 8.34, p < 0.01 Table 3-4.).

Table 3-4. ANOVA to determine significance of burn treatments on ANPP and Litter for field plots located at HVC, Highmont Tailings facility.

Model:	**ANPP = Burn Treatment (Fixed) + Quadrat (Error)**				
Effect					
	Sum-of-squares	Mean squares	df	F-Value	p
Burn Treatment	7381	3690	2	1.09	>0.05

Model:	**Litter = Burn Treatment (Fixed) + Quadrat (Error)**				
Effect					
	Sum-of-squares	Mean squares	df	F-Value	p
Burn Treatment	16630	8314	2	8.34	**<0.01**

Pairwise comparisons show a significant decrease in litter from the control to the ‘Burn’ treatment fifteen months postburn ($p < 0.05$, p.adj = <0.001, Figure 3.11B) These results suggest that burning alone or paired with additional amendments does not appear to significantly increase or decrease ANPP, but significantly decrease litter (Figure 3.11). The importance of these results suggests that burning aids to removing litter, while not reducing the productivity of the plant community which may have implications in enhancing diversity on site as seen in the results above.

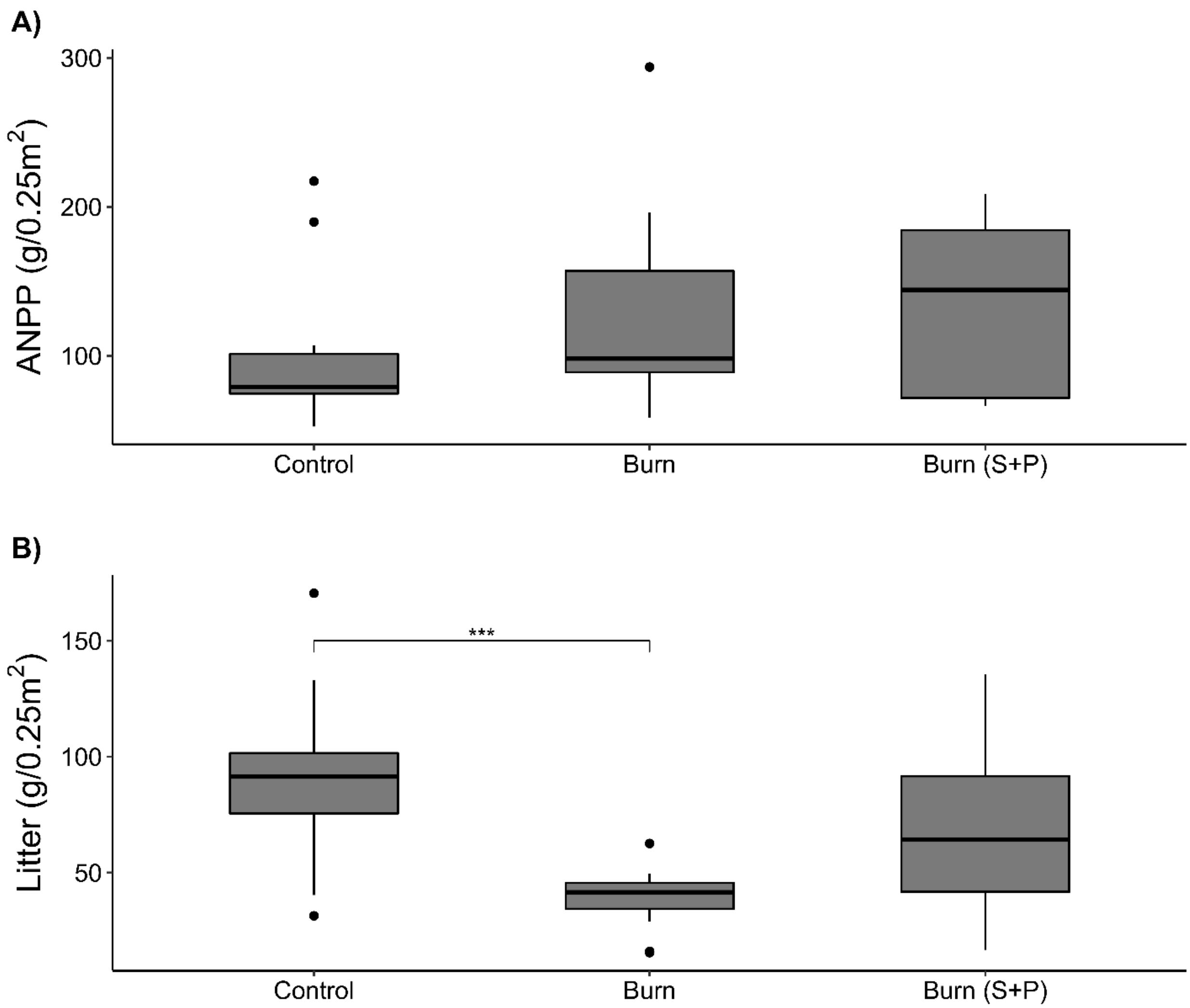


Figure 3.11. A) Aboveground net primary productivity (ANPP) and B) Litter by burn treatment, fifteen months postburn (n control = 12, n Burn = 12, n Burn(S+P) = 12). Pairwise comparisons analyzed treatment against control and p-values were adjusted with BH corrections. '*' $p < 0.05$, '**' $p < 0.01$, '***'$p < 0.001$. Non-significant values were not plotted. Burn (S+P) treatment was seeded and planted with trees and Burn treatment was only burned.

Plant productivity was further analyzed by examining ANPP across burn treatments by plant functional groups of forbs, non-desirable grass, and native grasses at fifteen months postburn. Burn treatment resulted in a significant effect when analyzing forb ANPP ($F = 3.54$, $p < 0.05$, Table 3-5, Figure 3.12). Productivity within the other categories did not result in any significant change. Post-hoc pairwise comparisons between burn treatments resulted in a significant increase of forb ANPP within the ‘Burn’ only treatment ($p < 0.05$, p.adj = 0.03). This result suggests that burning without the addition of amendments favors the productivity of forb production (Figure 3.12).

Table 3-5. ANOVA to determine significance of burn treatments on ANPP of Forbs, Non-desirable grass, and Native grass for field plots located at HVC, Highmont Tailings facility.

Model:	**Forb Biomass = Burn Treatment (Fixed) + Quadrat (Error)**				
Effect					
	Sum-of-squares	Mean squares	df	F-Value	p
Burn Treatment	12.223	6.11	2	3.54	**<0.05**
Model:	**Non-Desirable Grass Biomass = Burn Treatment (Fixed) + Quadrat (Error)**				
Effect					
	Sum-of-squares	Mean squares	df	F-Value	p
Burn Treatment	6533	3266	2	0.8	>0.05
Model:	**Native Grass Biomass = Burn Treatment (Fixed) + Quadrat (Error)**				
Effect					
	Sum-of-squares	Mean squares	df	F-Value	p
Burn Treatment	9.97	4.98	2	0.69	>0.05

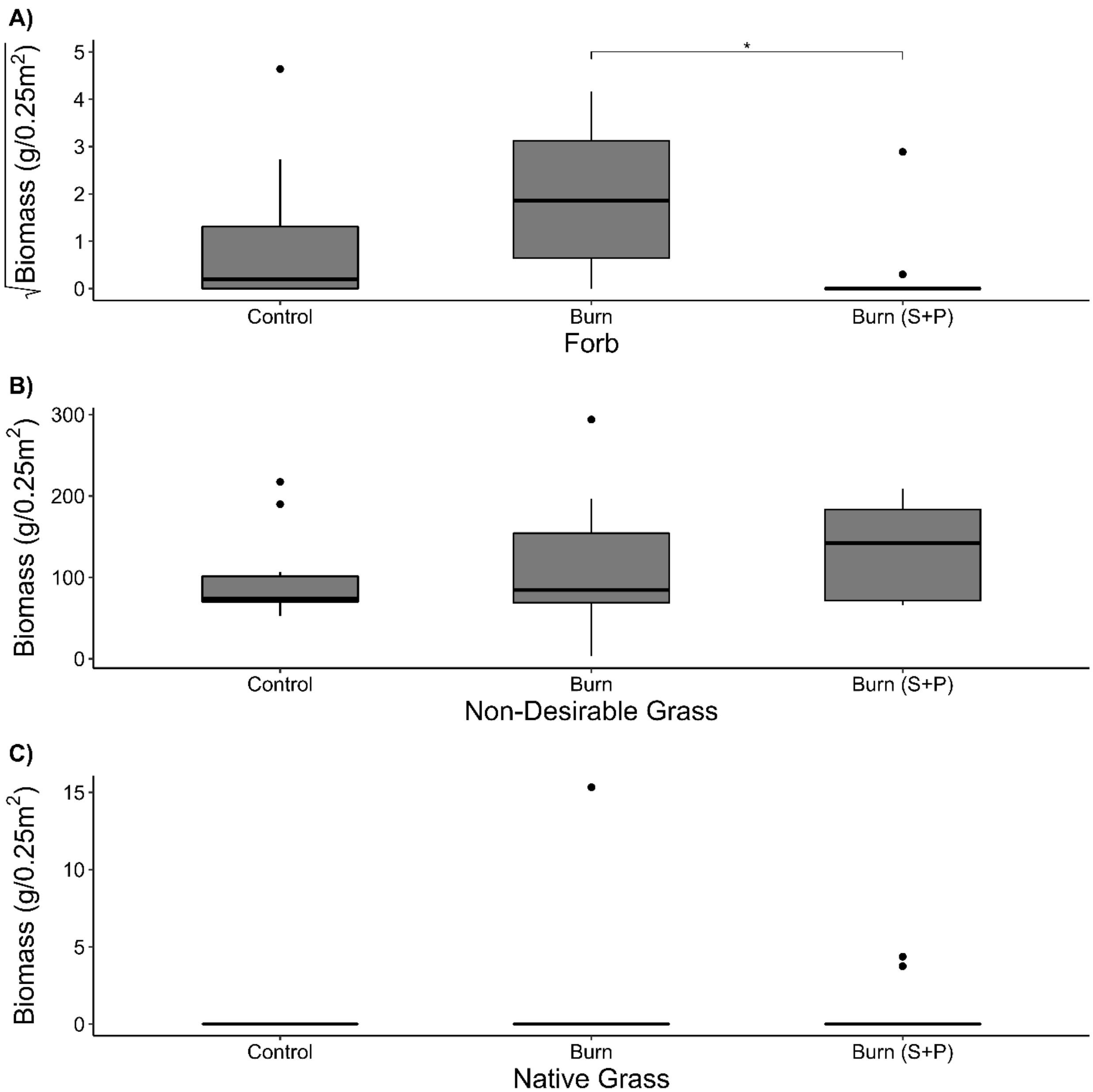


Figure 3.12. Aboveground net primary productivity (ANPP) of A) Forbs, B) Non-desirable grasses, and C) Native grasses by burn treatment, fifteen months postburn (n control = 12, n Burn = 12, n Burn (S+P) = 12). All pairwise comparisons were analyzed, and p-values were adjusted with BH corrections. '*' $p < 0.05$, '**' $p < 0.01$, '***'$p < 0.001$. Non-significant values were not plotted. Burn (S+P) treatment was seeded and planted with trees and Burn treatment was only burned.

Soil Elemental Analysis & pH Response to Burning

Linear mixed effect modeling resulted in no significant differences in concentrations of total nitrogen, carbon, or C:N ratio due to treatment effects. Timing as a factor, however, resulted in a significant effect across all soil elements (Table 3-6.). Pairwise comparisons between preburn to fifteen months postburn resulted in almost a twofold increase in total N ($F = 17.73$, $p < 0.01$) , total C, ($F = 23.35$, $p < 0.01$) and a significant increase in C:N ratio ($F = 26.68$, $p<0.01$) within the top fifteen cm of soil (Table 3-6, Figure 3.13).

Table 3-6. ANOVA to determine the significance of burn treatment on total N, total C, and C:N ratio.

Model:	Total N = Timing (Fixed) + Plot (Error)				
Effect					
	Sum-of-squares	Mean squares	df	F-Value	p
Timing	0.09	0.09	1	17.73	**<0.01**

Model:	Total C = Timing (Fixed) + Plot (Error)				
Effect					
	Sum-of-squares	Mean squares	df	F-Value	p
Timing	14.05	14.05	1	23.35	**<0.01**

Model:	C:N = Timing (Fixed) + Plot (Error)				
Effect					
	Sum-of-squares	Mean squares	df	F-Value	p
Timing	2.84	2.84	1	26.68	**<0.01**

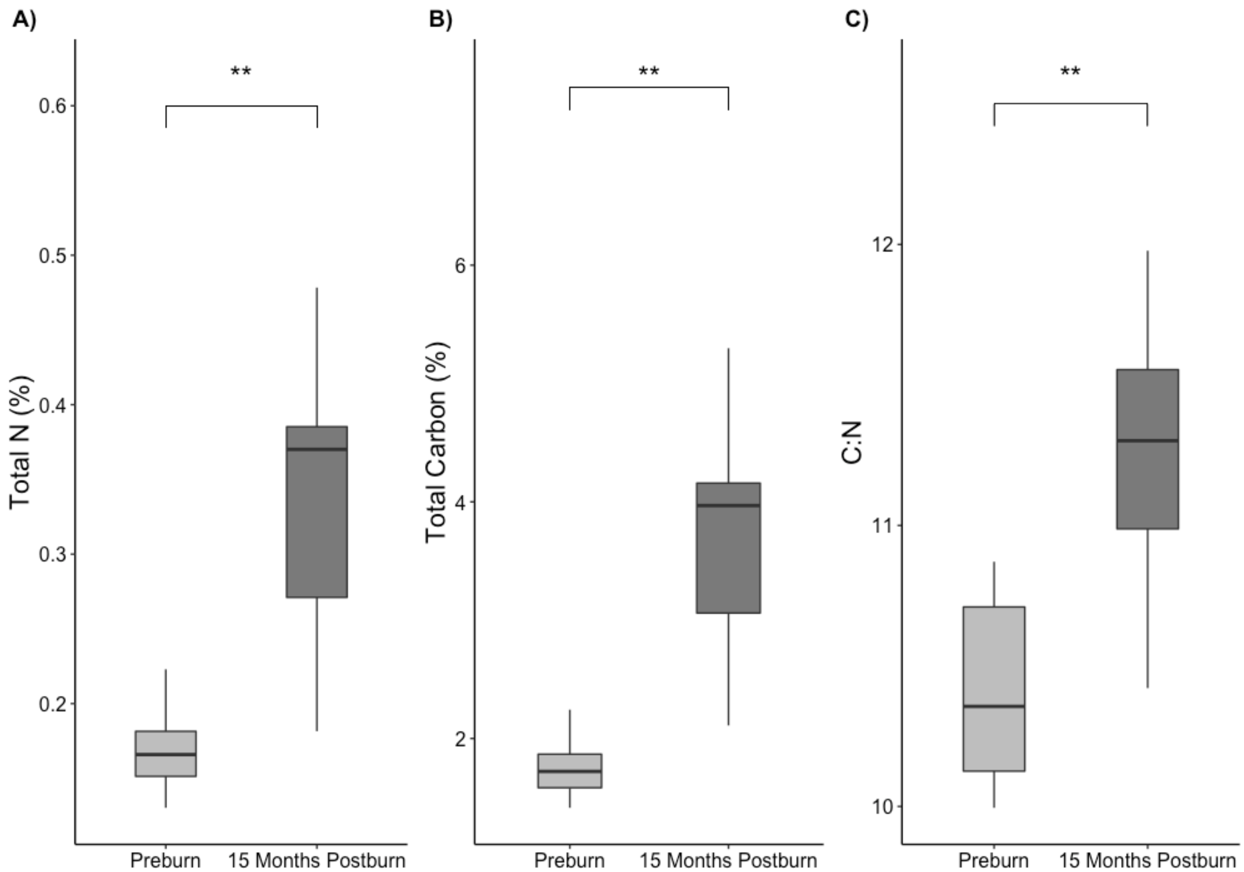


Figure 3.13. Comparisons of A) Total nitrogen, B) Total Carbon, and C) carbon to nitrogen (C:N) ratio (n preburn = 6, n fifteen months postburn = 9) for soils extracted from Highland Valley Copper, Highmont Tailings prior to burning and fifteen months after burning was completed. * = 0.05, ** = 0.01, *** = 0.001

These results indicate that soil nitrogen and carbon levels increased over time likely as a result of prescribed burning, generally.

pH values did not significantly differ due to burn treatment (Table 3-7).

Table 3-7. ANOVA to determine the significance of burn treatment pH

Model:	pH = Burn Treatment (Fixed) + Plot (Error)				
Effect					
	Sum-of-squares	Mean squares	df	F-Value	p
Treatment	0.08	0.04	2	1.89	0.17

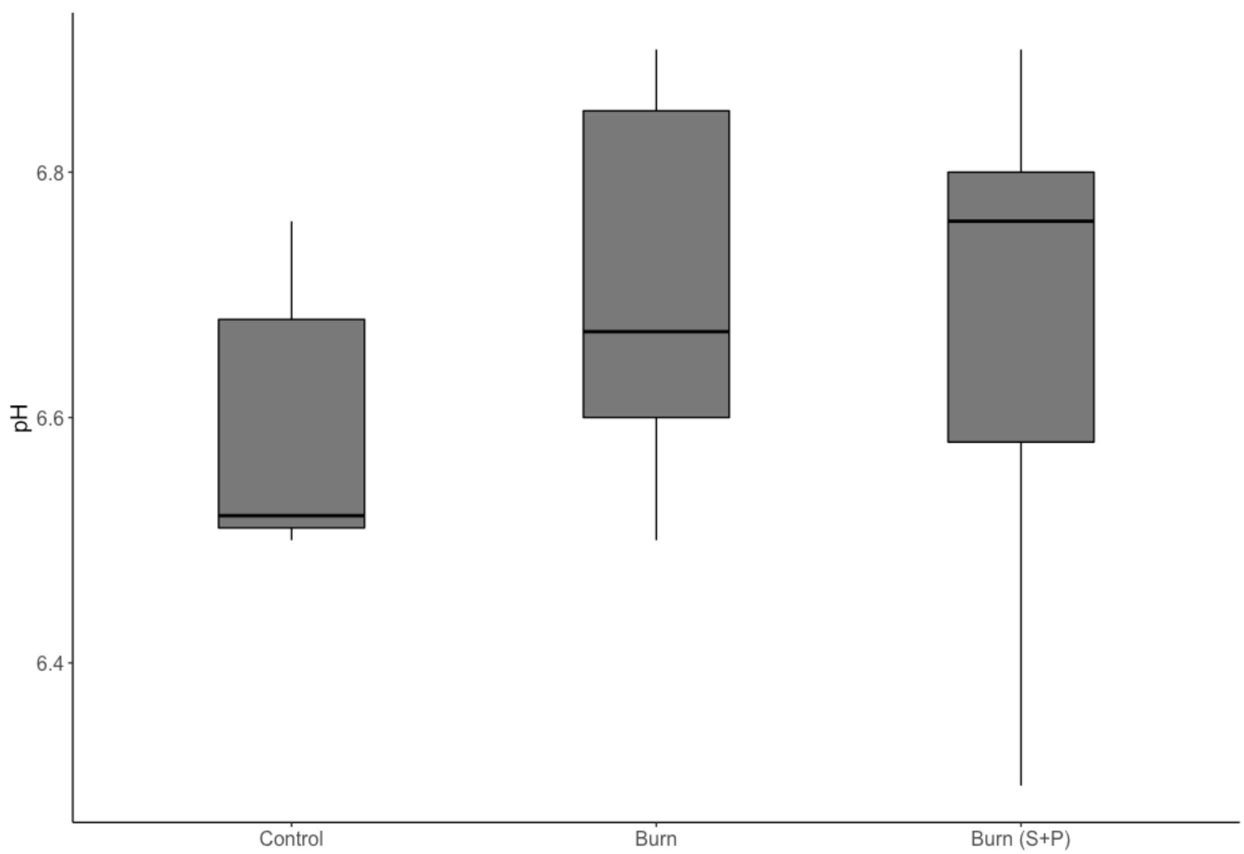


Figure 3.14. pH of the top 15cm of soil extracted fifteen months postburn from burn treatments (n = 9 for each group) located at Highland Valley Copper, Highmont Tailings. Burn (S+P) treatment was seeded and planted with trees and Burn treatment was only burned.

DISCUSSION

Impacts of Disturbance and Amendments on Diversity

Prescribed burning resulted in a significant but limited effect on the species diversity and richness. Species richness and Shannon-diversity when compared to the unburned controls was greater interestingly only within the 'Burn' treatment (Figure 3.6A). An increase in species diversity and richness following prescribed fire is a similar result in many studies (Sparks et al. 1998, Durigan et al. 2020). Additionally, I found that the amendments of seeding and tree planting after burning did not appear to have any significant effects. I suggest two ways to explain why this occurred. As no species losses occurred after prescribed burning, and no significant effects in richness or Shannon diversity were noted with the seeding amendment, the pre-fire composition appears to play a major factor in determining post-fire composition, especially with herbaceous covers that responded quickly to disturbance (Sparks et al. 1998). It is likely that due to the continued dominance and competitive exclusion by the heavy herbaceous cover of rhizomatous grasses, that native seedling establishment was limited and the increase in richness I observed was a direct result of species that were already part of the seedbank which comprised mostly forbs that were able to respond quickly and positively to disturbance (Figure 3.12A) (Kirkman et al. 2014, Swab et al. 2017). Secondly, as it was observed in Figure 3.4C, the non-desirable grass species responded extremely fast to the burning disturbance which likely resulted in the native seeded species being shaded out very soon after disturbance. The observation in richness and increase in forb cover that I observed was likely that of shade tolerant and tall lived species that were already part of the plant community and able to grow away from the shaded conditions that the seedlings failed to (Gommers et al. 2013). Evidence of this extreme competition for light and shade-avoidance response within the high-density monoculture could likely be observed in future studies comparing shoot to root development as more carbon is allocated towards shoot development to avoid being shaded out, in addition to exploring photosynthetically active radiation rates over time since disturbance (Gommers et al. 2013).

Litter Dynamics in the Plant Community

Impacts of prescribed burning resulted in changes to community-level divergence due to treatment and timing effects (Figure 3.7). Exploration of the factors predicted by random forest modelling confirmed that this divergence was largely due to changes resulting from the consumption of litter and increased cover of forbs (*Achillea millefolium)* after burning (Figure 3.9). Furthermore, litter was a significant factor in limiting plant diversity on site as a negative relationship between richness, evenness and diversity were all observed with respect to increasing levels of litter (Figure 3.10). In grassland plant communities, this result has been observed in many studies (Maret and Wilson 2005, Lamb 2008, Collins and Calabrese 2012). The significance of this result points towards the use of prescribed burning to reduce the amount of litter that provides barriers to seedling emergence as litter tends to alter the physical environment through intercepting light and shading seeds and seedlings, ultimately depressing germination and establishment (Facelli and Pickett 1991, Maret and Wilson 2005). In consideration of reducing litter, and providing the best changes for seedlings to germinate, Wang et al. (2021) found that fall burning resulted in greater impacts to community composition and ultimately a longer time to recover to preburn conditions and greater length of time with exposed soil surface. As limited success was found within the application of spring burning, burning in the fall may present the best opportunity to decrease levels of litter, while offering a prolonged period of reduced competition for new seedlings to establish.

Disturbance, Productivity and Litter

The effects of prescribed burning on total ANPP, and ANPP by functional group were consistent with findings from Scheintaub et al. (2009) and Augustine et al. (2010) within a semi-arid grassland which found neutral effects of burning on total ANPP and ANPP of perennial grasses, and increased ANPP of forbs (Figure 3.11). The neutral response in ANPP I observed may be a result of timing of burn as early season burns allow for more opportunity to recover through the rest of the growing season (Wang et al. 2021). As the goal is to transition this grassland away from a non-desirable and towards a native grassland community these results support the use of burning to at the least not enhance productivity of non-desirable grasses while opening a window for new species to enter. In examining Figure 3.11B., only fifteen months after burning litter levels are already beginning to approach levels of pre-disturbance shown by the control. These results continue to show just how productive this system is and how narrow the window is for new species to enter successfully and fight for space before being choked out by the established community.

Soil Elemental Analysis & pH Response to Fire

Elemental analysis results of the experiment indicate an overall increase in total nitrogen, carbon, and C:N ratio from preburn to fifteen-months post-burn. No significant differences between burn treatment types were observed as all treatments received the same burn treatment. The increase in total N and C into the system is an influence of the addition of water-soluble components of ash that become available for plants through burning (Pathak et al. 2017). In low intensity burning, N losses to the atmosphere are minimal when temperatures are below 200 °C, while biological and non-biological processes after burning are able to transform organic N into plant available inorganic N (NH_4 , NO_3) (Knicker 2007, Alcañiz et al. 2018). A similar result found by Rau et al. (2008) resulted in soil inorganic N (NH_4 , NO_3) significantly increasing post-burn, and remaining elevated for extended periods upwards of two years post-burn. These results are significant as they suggest that fire-driven nutrient losses were not observed, and clearly did not limit plant productivity as no decreases in ANPP were detected (Figure 3.11A). As NH^4 concentrations are commonly correlated with biomass consumption (Covington and Sackett 1992), prescribed burning in this instance has played a significant role in cycling nutrients from aboveground biomass and litter that would otherwise take years to breakdown (Brockway et al. 2002).

CONCLUSION

The results of this study show that this grassland ecosystem, in its present state of dominance by undesirable, hearty, highly productive grasses, is likely to return to a preburn state without continued disturbance of some kind. This is evidenced by the lack of establishment of native plants and the continued dominance of non-desirable grasses almost two years later. I found that burning did significantly increase diversity on site to some extent. The effects of burning to increase diversity appear though to be halted sharply due to other factors. I were able to expound on one significant factor: litter accumulation, that when paired with the high productivity on site, contributes significantly to restricting plant diversity within this community. The limited success I observed from the use of prescribed burning to enhance biodiversity may be a result of time of burning being conducted in the spring when moisture levels were high. To optimize the window for seeded species to enhance diversity on site, fall burning should be prescribed in addition to selecting species that are early colonizers and shade tolerant to best compete with the established plant community. Further research should consider the application of annual burning or an annual disturbance treatment in addition to timing of disturbance to examine the effects on ANPP of non-desirable species and the colonization rates of introduced species.

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Chapter 4 : TESTING PRESCRIBED BURNING INTENSITY IN A MESOCOSM AS A METHOD TO SHIFT A NON-DESIREABLE GRASS COMMUNITY TO A NATIVE PLANT COMMUNITY

ABSTRACT

Changes in plant diversity, abundance and soil nutrients following experimental disturbance were studied in experimental mesocosm units extracted from a twenty-five-year-old historically reclaimed grassland located at Highland Valley Copper mine in British Columbia (B.C.), Canada. Experimental mesocosm units were dominated by non desirable grass species such as *Elymus trachycaulus, Elymus lanceolatus, Thinopyrum intermedium* and *Bromus inermis.* The disturbance treatment was fire, represented by three fire intensities (low, moderate, high), replicated six times per treatment, and treatments were modified by the weight of dried litter applied to each mesocosm unit, along with the time each grass turf was burned. Clipping was added as an additional disturbance treatment to compare between fire disturbance treatments and undisturbed control plots. One day after the disturbance treatment, mesocosm units were seeded in order to examine effectiveness of plant establishment post-disturbance. Disturbance treatments resulted in higher overall alpha diversity, richness, evenness, beta diversity, and soil nitrogen and carbon. Plant community changes included colonization of seeded native forbs, grasses, and legumes in response to disturbance. Aboveground net primary productivity (ANPP) was slightly reduced within the clip and light burning disturbance treatments. Litter reduced plant diversity and ANPP, indicating that litter was a major factor in plant community dynamics. These results suggest a positive plant community response towards the use of disturbance to increase diversity of semi-arid grasslands, and to aid in shifting plant communities to preferred states.

INTRODUCTION

Fire is a natural ecological disturbance, but due to its heterogenous and environmentally specific behavior the effects on plant communities based on fire severity has not been well quantified (Duff et al. 2017). Field studies on fires often arise from opportunistic sampling and analysis where fires have occurred due to natural and anthropogenic agents rather than planned ignition. Such studies result in limitations with quantifying fire effects by limiting the project scope to postburn conditions often where no data has been collected prior to burning (McCarley et al. 2017). A mesocosm, microcosm or excised community aims to mimic a natural system while extracting ecologically relevant information and providing a simplified model for complex disturbances within particular ecosystems (Fraser and Keddy 1997). This study examines a mesocosm based approach to examine how fire disturbance can be used as a method to shift a non-desirable plant community to a native plant community. The experimental design focused on a gap in literature surrounding plant community, and soil nutrient response to fire severity effects.

Fire is a principal ecological process that influences the evolution of numerous plant species while acting as a mechanism to sustain structure, diversity and productivity of fire dependent ecosystems (Moritz et al. 2014). In grasslands, plant communities are primarily influenced by a combination of biotic and abiotic factors including fire, grazing, and climate (Collins and Calabrese 2012). The ecology of fire on the landscape works primarily by affecting and ultimately increasing the availability of resources such as light while resulting in increased nitrogen availability and nutrient cycling (Swanson et al. 2011). This in turn can modify relationships among species and change dominance in a community due to species specific responses to changes in these variables (Ghermandi et al. 2004, Collins and Calabrese 2012, Augustine et al. 2014).

Patterns of plant diversity are largely dependent on interactions between frequencies of disturbance and above-ground biomass of the vegetation (Pekin et al. 2012). In highly productive sites, biomass and litter accumulation that is left in a state without disturbance or some form of reduction may ultimately restrict above ground net primary productivity (ANPP), species richness, and favor tall lived species reducing functional diversity in life form (Foster and Gross, Peco et al. 2012). Reduction in plant diversity can largely be attributed to biomass accumulation in the understory sequestering limiting nutrients and restricting light availability to the environment below, resulting in competitive exclusion from tall-lived species (Grime 1973, Pekin et al. 2012). North American oak stands that were frequently burned resulted in nearly double the species richness of less frequently burned stands suggesting fire prevented competitive exclusion of grasses and forbs by taller lived species such as trees and shrubs (Peterson and Reich 2008). Similarly with highly productive grasslands a disturbance such as fire is an important determinant in increasing richness of grasses and forbs for the community through reducing competitive exclusion, evidenced by a > 50% reduction in grass species richness in the absence of disturbance (Fynn et al. 2004).

As species richness of vegetation tends to peak within a few years following fire, life form diversity can change significantly over time with respect to disturbance return intervals. Species with shorter juvenile periods able to mature and set seed will be favored in higher disturbance regime areas where obligate seeders might be reduced before maturation (Pekin et al. 2012). Fire plays a significant role in plant community composition and structuring grassland ecosystems. Post fire conditions often favor establishment of new species through various abiotic ecosystem changes such as: decreased soil moisture, removal of accumulated litter and subsequent release of nutrients immobilized within the dead plant tissue, increased solar radiation to the ground, and allowing a period of reduced competition (Brockway et al. 2002, Scheintaub et al. 2009, Pekin et al. 2012).

Beyond plant community responses, fire in semi-arid and arid ecosystems has been shown to increase the availability of inorganic N in the first post-burn year and extended periods beyond the fire. This increase in plant available nitrogen can influence regrowth, seedling establishment of native species, invasion of annual plants, and ultimately site recovery (Rau et al. 2007, Augustine et al. 2014), extending its use in reclamation of mine spoils where nitrogen is limited.

Despite the ecological benefits and outcomes of prescribed fire, its application within the reclamation and restoration setting is rarely utilized (McKenna et al. 2019) but its efficacy as a management tool is rapidly changing and often times is used to manage rangelands and fuel loads in fire prone ecosystems (Taylor 2003, Penman et al. 2011). Fire managers and ecologists are utilizing burning in Canadian national parks to reduce fire risk or reintroduce disturbance to an ecosystem for management purposes (Scheintaub et al. 2009, Sutherland 2019). There is a lack of research however, on how fire intensity on a controlled scale may affect plant and soil community responses.

The purpose of this research was to determine the relative effect that fire disturbance and fire intensity plays on a twenty-five-year-old historically reclaimed plant community, and to examine the ability of a six-species plant mixture, to establish in post-fire conditions. The goal of burning paired with seeding is proposed as an aid to shift an undesirable plant community dominated by largely fast growing, non-desirable grass species (*Elymus trachycaulus*, *Bromus inermis*, and *Thinopyrum intermedium*) to a native plant community more typical of local grasslands. The six plant species selected for our experiment were *Castilleja miniata* (common red paintbrush), *Gaillardia aristata.* (brown-eyed susan), *Festuca campestris* (rough fescue), *Festuca saximontana* (rocky mountain fescue), *Oxytropis campestris* (field locoweed) and *Lupinus arcticus* (arctic lupine). I chose these species for a number of reasons: (1) To examine functional group responses to disturbance, (2) They represent common species found within B.C.'s upper grassland communities, (3) They align with the desired end land use reclamation goal objectives set out by Teck Highland Valley Copper and Indigenous project partners (Nlaka'pamux nation), and (4) They are expected to tolerate site conditions including high elevations up to 1500 m and, neutral to slightly alkaline soils, while also holding characteristics of drought tolerance and ease of establishment (Dobb and Burton 2012).

A mesocosm experiment may ease difficulty of studying the effects of fire on plant and soil communities due to the spatially heterogenous behaviour of fires that occur in the wild due to changing environmental conditions. Ecosystem responses correlated with measures of fire intensity can more accurately be demonstrated and understood within controlled mesocosm experiments. The information produced from this study will be of most interest to aid future researchers and resource managers when making decisions on how to utilize fire intensity as a predictive tool in reclamation and restoration activities.

A mesocosm experiment was designed to answer three questions: (1) What role does fire intensity play in the vegetative community with respect to increasing biodiversity and establishment of native species? (2) Does fire intensity effect soil nutrients such as total N, and total C? and (3) How does fire intensity effect the establishment of early and late successional grass, forb, and legume species?

METHODS

Term Clarification

Regarding the quantification and the characterization of post-fire effects, there exists a lack of concrete terminology surrounding the terms *fire intensity* and *fire severity* (Keeley 2009). For the purposes of my research and future research, the most important aspects of prescribed burning come down to replicability. This research was conducted under the understanding that fire intensity translates into fire severity such that I can quantify and modify variables surrounding intensity to result in scaled severity.

Fire intensity for the purpose of this research is restricted to a measure of energy output by fire. Fire intensity was modified to be a function of residence time (heating duration), plant dryness, and organic matter available for combustion (fuel) (Neary et al. 1999). It should be noted that other factors including pre-fire species composition, topography, substrate, and climate will have some effect on how fire intensity translates into fire severity (Keeley 2009).

Fire severity for the purpose of this research represents a quantification of how fire intensity affected the ecosystem. More specifically, fire intensity was used to match the empirical observations of fire severity that centres on the loss of aboveground biomass and ash characteristics. The table below represents a fire severity matrix adapted and modified from Keeley (2009) and Dobb and Burton (2012).

Table 4-1. Fire severity matrix related to above ground biomass consumption adapted from Keeley (2009) and Dobb and Burton (2012).

Fire Severity	Description
Low Severity	Surface litter scorched, charred, consumed
Moderate Severity	All understory plants charred or consumed, all litter consumed, light colored ash
High Severity	All understory plants consumed, all litter consumed, larger quantity of light-colored ash

Mesocosm Unit Extraction Site

Mesocosm experimental units were extracted in August of 2019, from the Historic Highmont Tailings Storage Facility (TSF), located approximately five kilometers west of Logan Lake, British Columbia (B.C.) within Highland Valley Copper Mine (HVC; UTM Z10;647739E, 5588766N, elevation 1500m, Figure 4.1).

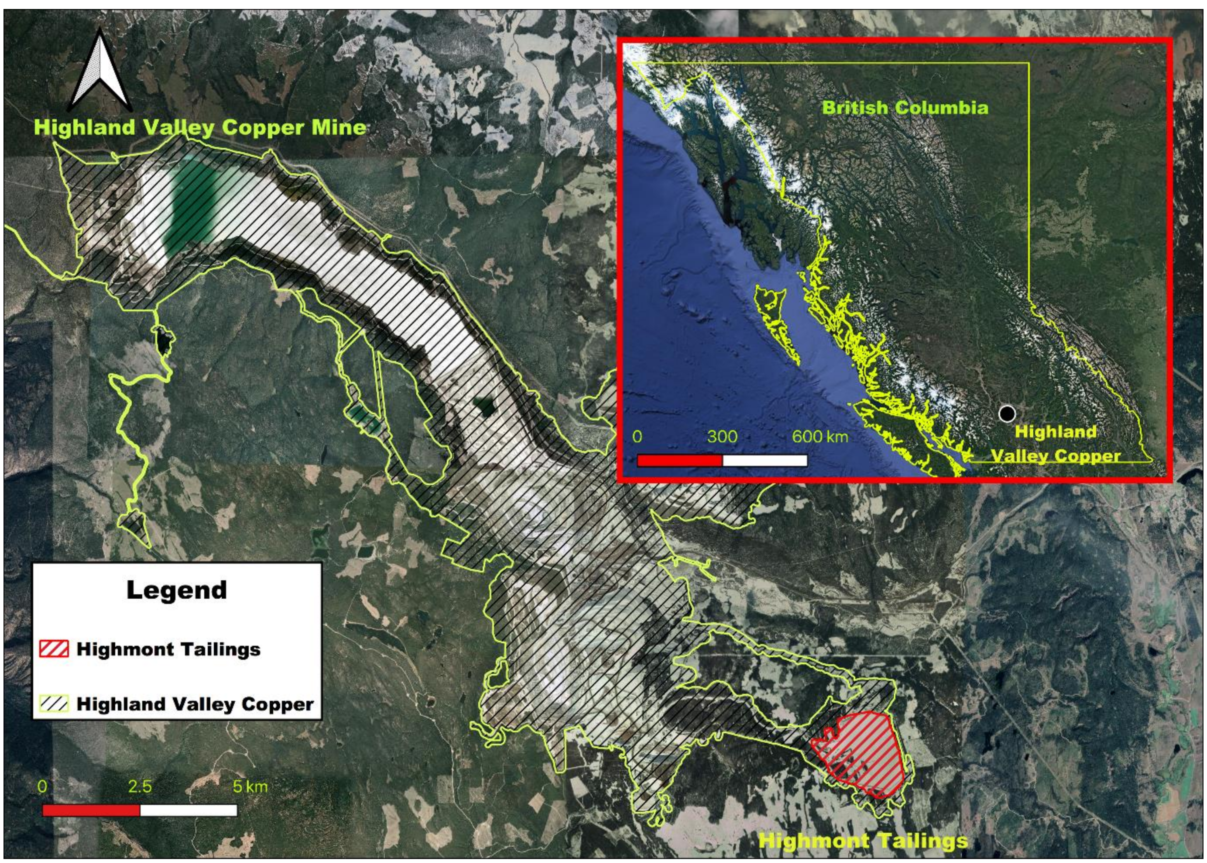

Figure 4.1. Mesocosm unit extraction site located within Highland Valley Copper Mine, Highmont Tailings Storage Facility, British Columbia, Canada.

Highmont Tailings is located within the Montane Spruce MSxk2 (very dry, cool) biogeoclimatic zone (Government of British Columbia Ministry of Forests 1991). This location is characterized by cold winters and moderately short, warm summers. The mean annual temperature is 3 – 4.5°C and mean annual precipitation ranges from 380 – 900mm (BC Climate Explorer 2021).

The history of the historic Highmont Tailings storage facility represents twenty-five years of reclamation work. Notable reclamation efforts include a series of seeding trials in 2008 (35kg/ha) paired with biosolid application (200 dt/ha) to aid in establishing vegetative cover onto unamended tailings. The selected seeds represent various introduced, long-lived, sod-forming wheat grasses often utilized for agronomic purposes due to their heartiness and ability to grow in nutrient limited, and water limited environments.

The plant community in the study area represents a low diversity, patchy landscape that is primarily composed of a few dominant, and highly productive non-desirable grasses (*Elymus trachycaulus, Agropyron spp., Thinopyrum intermedium & Bromus inermis*) that make up the majority of the plant community. Additional species include a very low abundance of non-leguminous forbs (*Achillea millefolium & Sisymbrium altissimum*). These species even though considered native, are common to reclamation projects due to their positive response to poorly developed, well drained soils. The species listed above throughout the paper are listed as non-desirable due to the updated land use plan set out by the mine company in partnership with the Nlaka'pamux community. This updated land use plan places more focus on increasing biodiversity and shifting the site trajectory towards desired species that represent locally native bunchgrasses, forbs, and legumes more indicative of an undisturbed grassland for the province.

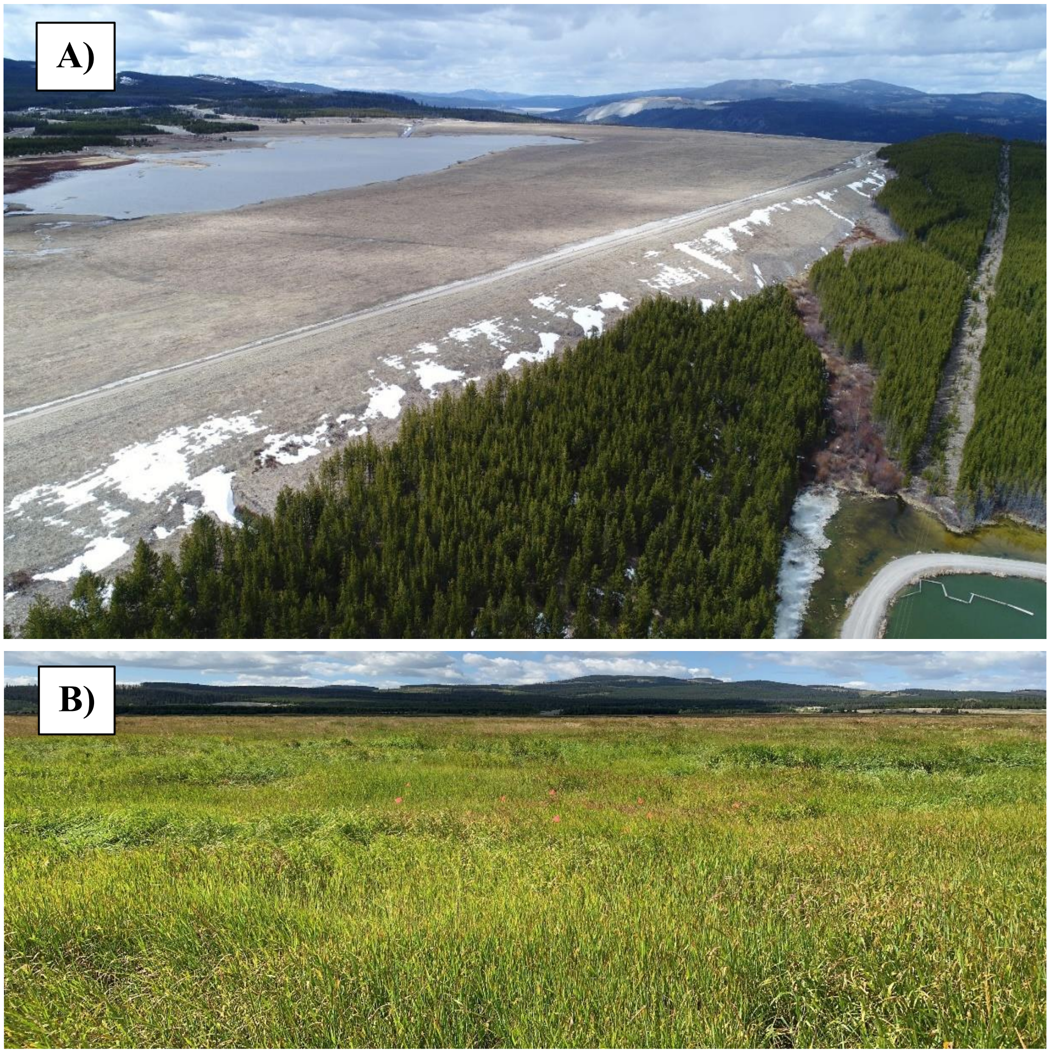

Figure 4.2. A) Aerial photo of the Historic Highmont Tailings dry stack storage at Highland Valley Copper, April 2019. B) Current vegetative cover during peak growing season at Highmont Tailings Storage Facility, August 2019.

Experimental Design

The experiment was established in the Summer of 2019 and treatments were applied in January 2020 and ran for 227 days (approximately seven months). The experimental design was a randomized complete block design with a single factor (disturbance treatment), with five levels (control, clip, light burn, moderate burn, heavy burn) and six replicates per level, for a total of thirty individual experimental mesocosm units. Clipping disturbance treatment was added to assist in differentiating between fire disturbance response and disturbance response generally. Each experimental unit was hand-seeded with a custom native seed mix at a rate of 200 seeds/spp./mesocosm unit after disturbance treatment (~ 2400 seeds / m^2 or ~ 1200 seeds / mesocosm unit) (Table 4-2). All seeds were purchased from commercial sources. See Appendix D (Table D-2) for results of germination trial and information about seed source. Treatments were randomly assigned to each block and mesocosm unit.

Seed Selection, Preparation & Seeding Rate

A total of two native grasses, two native forbs, and two native legumes were selected for seed application in the mesocosm experiment (Table 4-2). Within each of these three functional groups an early and mid or late successional species was chosen based on their expected level of tolerance to site conditions including neutral to slightly alkaline soils, elevation range (1500 m), drought tolerance, and ease of establishment (Dobb and Burton 2012). The native species also represent common species found within B.C.'s grassland communities, in addition to aligning with target species within the end land use goal of the mine.

Prior to the application of the hard coated legume species onto each mesocosm unit, seeds were scarified using sandpaper and water imbued for five hours (Baskin and Baskin 1998, Kimura and Islam 2012). All seeds were then placed into an envelope packet along with 25 mg of sand to help achieve even dispersal when sowing.

Based on the results of the germination trial (see Appendix D, Table D-1 & D-2), the pure live seed (PLS) rate obtained was approximately (1873 PLS/m^2). This seeding rate represents the upper limit that has been placed approximately at 1400 PLS/m^2 (Barr et al. 2017) and 750 – 1500 PLS/m^2 for degraded grasslands to optimize richness and diversity (Burton et al. 2006). Germination data from *Castilleja miniata* was excluded from the PLS calculation due to lack of any germination.

Table 4-2. List of plant species selected for the mesocosm experiment indicating successional status and functional group

#	Common Name	Scientific Name	Type	Succession
1	Common Paintbrush	*Castilleja miniata*	Native Forb	Late
2	Brown-eyed Susan	*Gaillardia aristata*	Native Forb	Early-Mid
3	Rough Fescue	*Festuca campestris*	Native Grass	Mid-Late
4	Rocky Mountain Fescue	*Festuca saximontana*	Native Grass	Early
5	Field Locoweed	*Oxytropis campestris*	Native Legume	Early-Mid
6	Arctic Lupine	*Lupinus arcticus*	Native Legume	Early

Mesocosms

The indoor mesocosms used to test the effects of fire intensity on the plant community were extracted as intact ‘grass-turf’ units and placed into 102-liter HDX Tough Storage Bins™ (Figure 4.3). All mesocosm units were then transported back to Thompson Rivers University (TRU) research greenhouse. The experiment was conducted under controlled greenhouse conditions operated by Argus™ control systems (natural and artificial light: day/night 18h/6h; temperature: day/night 21°C; humidity: 50-60%).

The bins and turf sizes were selected to obtain an approximate area of 0.25 m^2 (Bin dimensions: L0.56 m by W0.46 m by H0.38 m) for vegetation analysis purposes and to ensure each grass turf contained intact root systems and soil profile. The soil profile within each mesocosm contained an A-horizon layer ranging from approximately 2 - 3 cm, with the subsequent layer representing fine textured mine-tailings. Each mesocosm container had a total of fifteen 1 cm diameter drainage holes, in addition to landscape fabric that was placed on the bottom to stop the release of fine textured tailings during watering events.

The mesocosms were free draining to allow for natural soil moisture profiles and watered as needed. Plants were monitored daily for signs of stress and wilting within the greenhouse. The typical watering schedule included approximately three times a week during winter months and every second day during summer months. Increased watering in summer was essential due to the extreme observed temperatures within the research greenhouse.

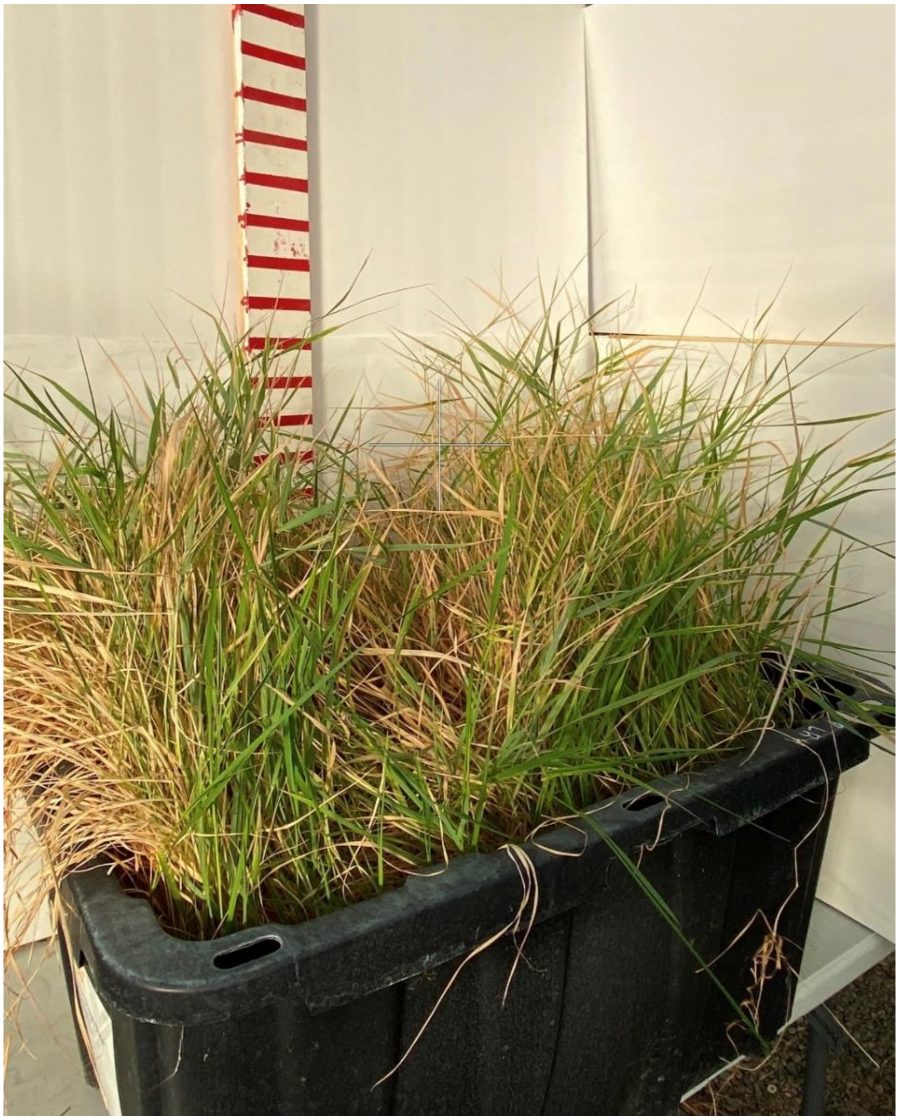

Figure 4.3. Extracted Mesocosm grass turf from Highmont Tailings Storage Facility, Highland Valley Copper Mine, British Columbia, Canada.

Fire Treatment

Fire intensity treatments were modified through amending the weight of dried litter applied to each mesocosm unit, along with modifying the time each grass turf was burned with a cast iron head, propane, Tiger Torch™ (Model No. 95-B)(Figure 4.4). The litter that was applied to each mesocosm was first quantified by taking dry weight, and then reapplied ensuring there were no seed heads on any applied litter to mitigate the introduction of additional seeds. The cast iron head was held at the same height (30 cm) above each unit and a ‘S’ type motion was used for torching each unit. Gas pressure and flame intensity remained constant throughout the process and was regulated using the controls on the Tiger Torch™.

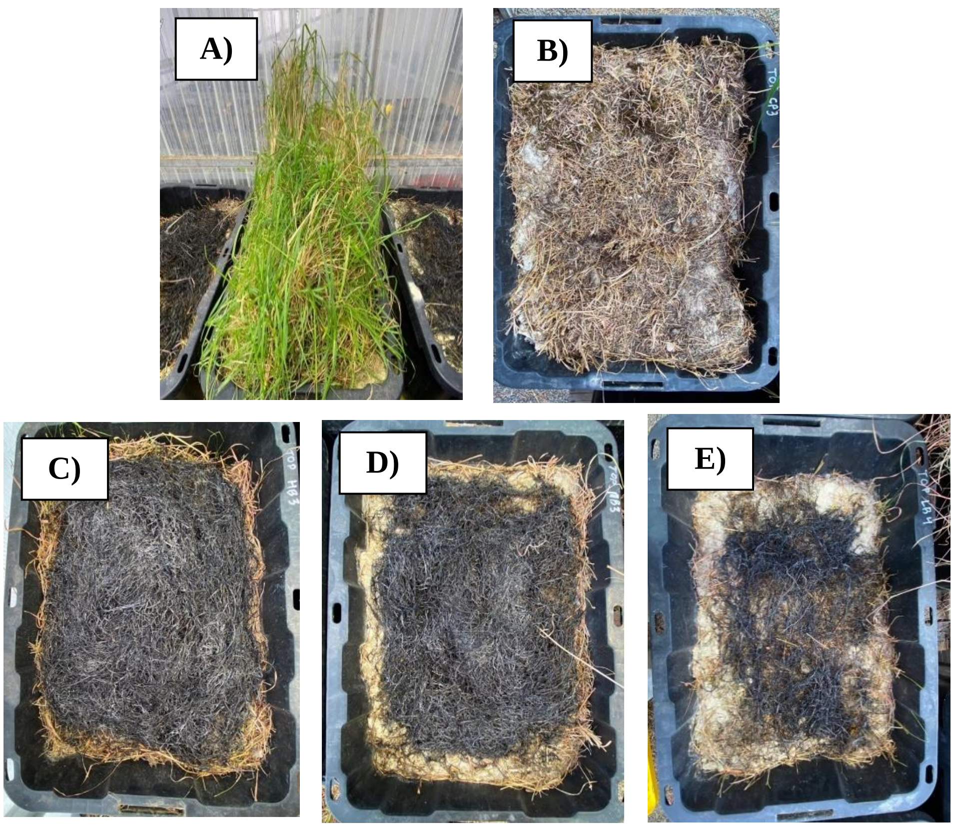

Figure 4.4. Mesocosm units and their respective treatments; A) Control, B) Clip (2cm height), C) High Intensity (200g litter applied, 20 s burned), D) Moderate Intensity (150g litter applied, 15 s burned), E) Low Intensity (50g litter applied, 10 s burned). All mesocosm units were seeded at the same time, and at the same rate after treatment was applied.

Flame temperature was recorded within each mesocosm unit using self-constructed pyrometers utilizing Omegalaq™ temperature sensitive paints ranging from 107 °C to 510 °C. The temperature sensitive paints were applied at gradations of approximately 30 °C and painted on pieces of tin that were placed at the center of each mesocosm unit. Each pyrometer was analyzed after the burn treatment and results collected by a single observer. Temperature sensitive paints were determined to reach their specified target when a sharp drip was observed indicating melting, in addition to the loss of the original color and a shift from matte to glossy finish after treatment (Figure 4.5).

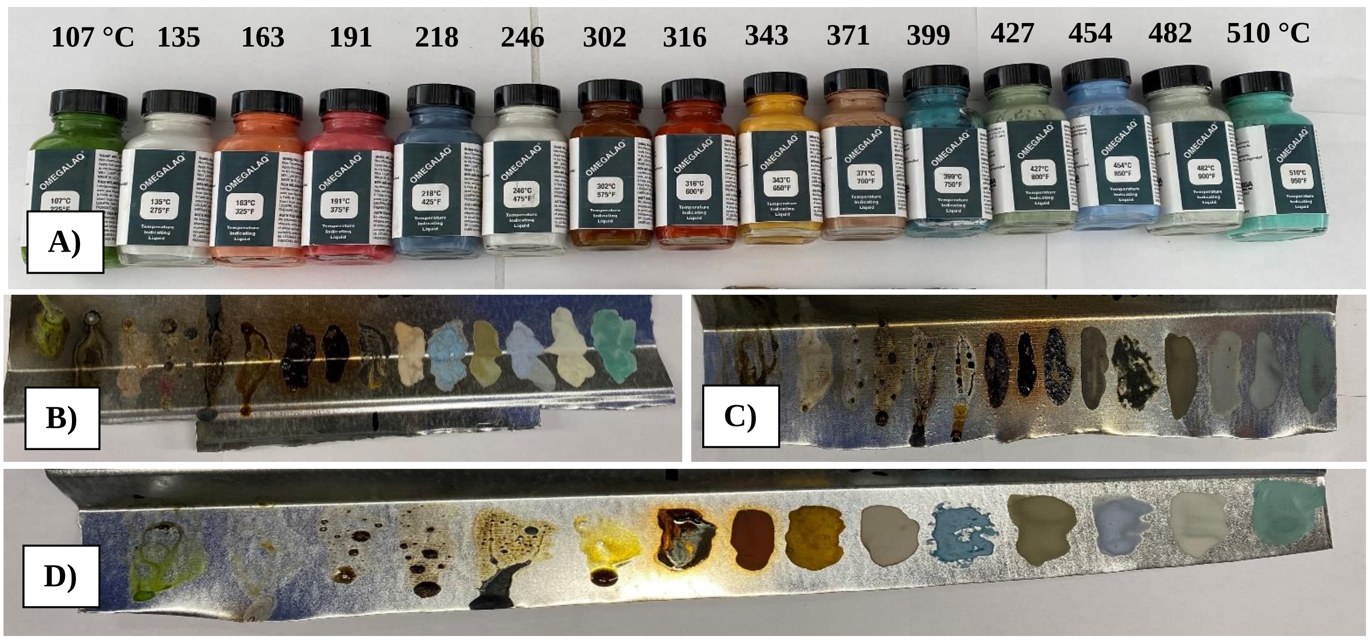

Figure 4.5. Omegalaq™ temperature sensitive paints applied at gradations of approximately 30 °C used to quantify fire temperature. A) Omegalaq™ paints from lowest to highest temperature. B) High severity burn analyzed at approximately 343 °C. C) Moderate severity burn analyzed at approximately 343 °C. D) Low severity burn analyzed at approximately 302 °C.

Vegetation Assessment & Harvesting

Vegetation measurements were collected within each mesocosm unit prior to burning, using absolute canopy cover estimation on the entire grass turf, approximating a 0.5 m by 0.5 m quadrat. Additionally, above-ground biomass and litter were collected from each mesocosm unit besides the control to quantify the above ground net primary productivity (ANPP) as a baseline for productivity. Mesocosms were then allowed to grow for seven months, after which above-ground biomass and litter was collected again. The plants were harvested as close to the soil surface as possible and separated by species to quantify ANPP. Litter was collected after ANPP was collected by scraping dead material off the soil surface. All plants were oven-dried for approximately 48h at 65 °C and weighed to a constant weight to determine dry matter biomass separated by above ground biomass and litter.

Vegetation community assessment via absolute canopy cover estimation was completed pre-disturbance, one-month post, three-months post, six-months post and prior to final harvest (seven-months post). To better understand the plant community dynamics, evenness and dominance was calculated respectively using the Shannon-Weiner index which accounts for richness and evenness, and the Simpson index which analyzes dominance. Species richness was considered the number of species present in each grass turf at the time of sampling.

Soil Sampling, Elemental Analysis & pH

A single soil sample was taken at random from each mesocosm unit at all time intervals specified in the above paragraph. Soil samples were extracted using a stainless-steel soil sampling probe with a core diameter of 2 cm. Each core extracted the entire soil profile of the mesocosm unit and was separated into the top 10 cm and bottom 10 cm for analysis (Figure 4.6). Soils were analyzed for total nitrogen (TN), total carbon (TC), C:N ratio, and pH using a Thermo Scientific Flash*Smart*™ Elemental Analyzer and a Fisherbrand™ accumet™ AB150 benchtop pH meter.

Soil preparation for elemental analysis included air drying within a Yamato™ drying oven (model DKN812) for 48 hours at 65°C to remove any moisture. After drying, approximately 10-15 mg of soil was weighed and placed into small tin capsules for placement into the elemental analyzer auto-sampling wheel. A total of three technical replicates were taken from each soil sample to ensure quality of analysis, resulting in a total of 868 individual samples run. In addition to examining each technical replicate against one another, Organic Analytical Standards (OAS) with known nitrogen and carbon values provided by Thermo Scientific™ were analyzed to ensure accurate estimation of elemental analysis.

Soil pH was measured in an aqueous matrix using a 2:1 water to soil ratio (Carter and Gregorich 2007). Air-dried soil was mixed and shaken with deionized water for one minute and then placed in a centrifuge and run at 4000rpm for five minutes. A Fisherbrand™ accumet™ AB150 benchtop pH meter was then calibrated with a pH 4, 7, 10 solution and used for analysis.

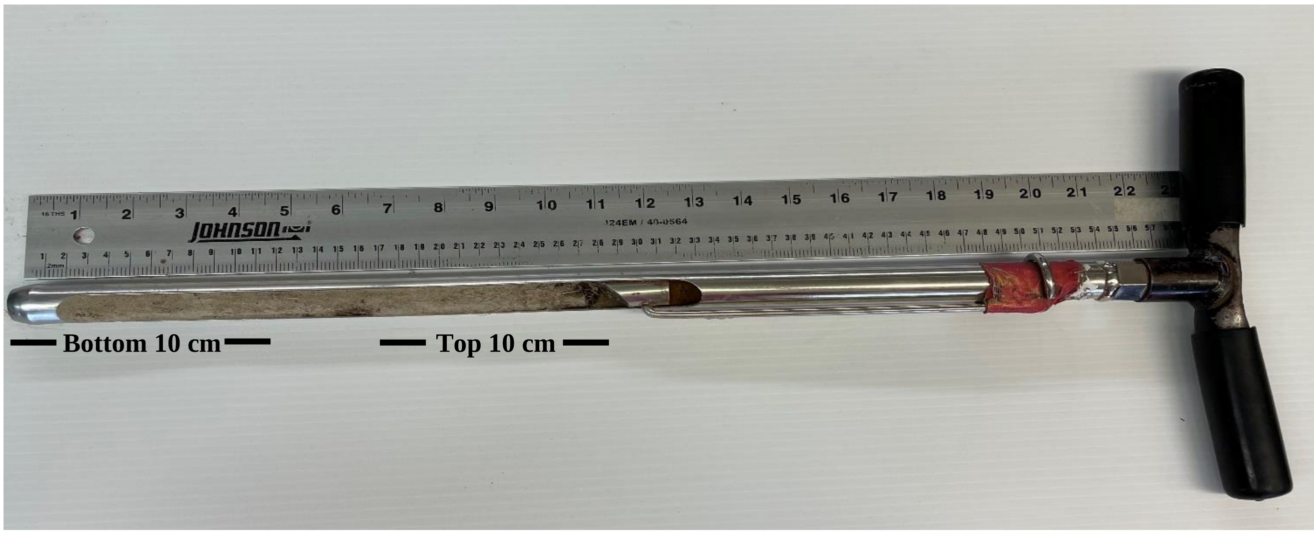

Figure 4.6. An intact soil core extracted from a mesocosm unit. The top 10 cm and bottom 10 cm was separated and used for soil analyses.

Statistical Analysis

All statistical analyses and figures were produced using R for Statistical Computing (R Core Team 2021). In all cases, significance was defined by $p < 0.05$. Data were analyzed using mixed model of analysis of variance using the 'lmer' function from the package "lme4". For all analyses completed, the random effect was the specific mesocosm from which the measurements were performed. Fixed effects for all models were extracted through running an analysis of variance (ANOVA) on the selected model. Post hoc analysis was done by completing pairwise comparisons and the p-values were adjusted with Benjamini-Hochberg (BH) corrections (Benjamini and Hochberg 1995).

All linear mixed effects models used were first checked to meet the assumptions of normally distributed residuals, and homogeneity of variance. Transformations of the data paired with non-parametric methods were used when data did not meet the above assumptions.

Plant cover data from each mesocosm unit was first analyzed descriptively by examining species richness, Shannon-Weiner and Simpson diversity indices using the ‘vegan’ package in R for statistical computing. Shannon diversity, Simpson’s index and species richness was analyzed comparatively between disturbance treatments and timing using linear mixed effect modeling.

Data normalization was completed on ANPP data to meet the assumptions of normality. Fifteen months postburn and pre-disturbance ANPP data for each mesocosm was normalized against its paired control ANPP weight at fifteen months postburn.

To examine the relationship between burning, litter biomass and ANPP, the relationship was plotted as outlined by Scheintaub et al. (2009). Only data from burn treatments was plotted against litter to examine the relationship of ANPP from pre-disturbance to project completion at 7-months postburn. To examine the relationship between burning, litter biomass and alpha diversity, the relationships were analyzed. Alpha diversity metrics were calculated using Richness, Shannon-diversity, and Simpson-diversity. All metrics were analyzed but only Shannon-Diversity was plotted for visual representation as all diversity metrics represented the same relationship.

A permutational multivariate analysis of variance (PERMANOVA) analyzing Bray-Curtis dissimilarity was used to assess community-level divergence between treatments and timing. This index is bound between zero and one, with zero indicating complete similarity in relative abundance of all species, while one indicates that no species are shared between the samples. The ‘adonis’ function in the ‘vegan’ package in R was used to complete this analysis. Species assemblages were normalized first using the Hellinger method. Bray-Curtis dissimilarity distances were then extracted in R to produce a boxplot to display dissimilarities between factors and examine post hoc comparisons.

Soil data was analyzed using a Flash*Smart*™ Elemental Analyzer that returns total concentrations for various major elements. Total carbon, nitrogen, and carbon to nitrogen (C:N) ratio were analyzed comparatively between disturbance treatments, timing from pre disturbance to post disturbance and level of soil depth using linear mixed effect modeling. Assumptions for running linear mixed effect models for each elemental concentration along with C:N ratio were validated, and no data transformations were needed.

RESULTS

Disturbance and Alpha Diversity

Disturbance significantly impacted all alpha diversity metrics with respect to analyzing the factor of disturbance treatment alone (Figure 4.7, A-C). The interactive effect between disturbance treatment and timing resulted in only significant differences being found within Shannon diversity and species richness (Figure 4.7, D-F).

Comparisons of burn treatments when examining Shannon and Simpsons diversity to the control resulted in a significant increase in diversity within the clip, light, and moderate burn severity treatments (Figure 4.7A, B). A similar, but stronger trend was observed such that species richness increased significantly across all disturbance treatments when compared to the control (Figure 4.7C). The significance of these results indicates that light to moderate disturbance treatment generally resulted in an increase in diversity, whereas heavy burning did not significantly increase diversity.

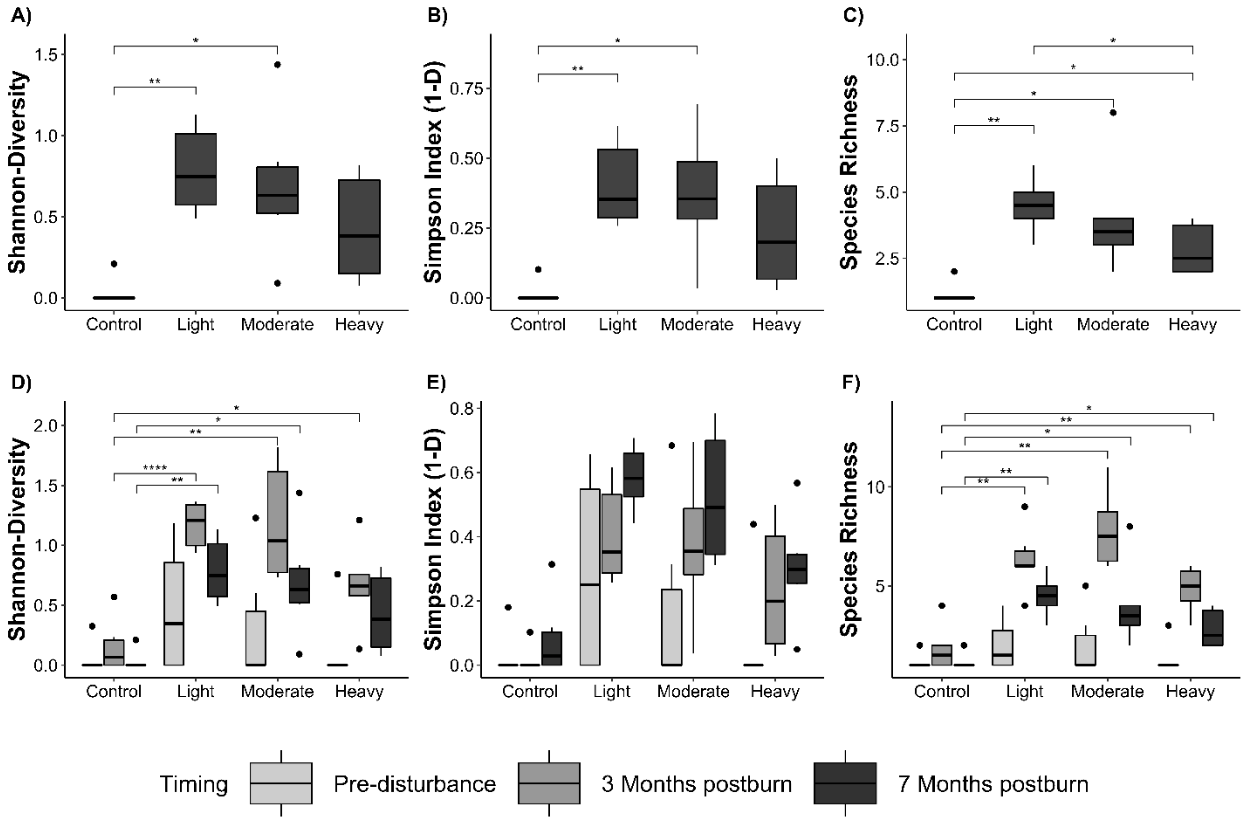

Figure 4.7. Shannon-Diversity, Simpson Index, and Species Richness as an effect of burning treatments (n = 6 for all treatments) at seven months postburn (A-C), and analysis of interaction effects between timing and burn treatments (D-F). All Pairwise comparisons were conducted in A-C, and pairwise comparisons to control were conducted in D-F. p values were adjusted with BH corrections. '*' $p < 0.05$, '**' $p < 0.01$, '***' $p < 0.001$.

The interactions between timing and disturbance treatment were significant when examining Shannon diversity and species richness (Figure 4.7D, F). Maximum Shannon diversity and species richness was observed and significantly different within the three-month postburn period in all disturbance treatments when compared to the control. This result indicates an increasing trend in diversity up until the third month, followed by a marked decreasing trend in Shannon diversity and species richness nearing the end of the experiment. In all disturbance treatments over time with respect to Shannon diversity and species richness, a humpback typed trend is observed such that diversity is maximized in the middle of the experiment in terms of timing and burning treatment.

Functional Group Analysis & Community Species Assemblage

Plant percent cover increased slightly due to the factor of timing across disturbance treatments (Table 4-3). Only models resulting in significant findings were posted in Table 4-3. See Appendix E (Table E-1.) for a plant inventory by functional group and classification of species as per this study. Cover of non-desirable grass, timing between pre-disturbance and seven-month post burn resulted in a significant effect ($F = 8.3862$, $p < 0.001$). This was also the case when analyzing cover of native grasses and ruderal herbs ($F = 5.1158$, $p<0.05$, $F = 13.479$, $p<0.001$) respectively. Pairwise comparisons within treatment groups were completed to determine the significant differences between treatments (Figure 4.8).

Pairwise comparisons between disturbance treatments and timing show greater cover of non-desirable grass from pre-disturbance to seven-month postburn (Figure 4.8). Observationally, as disturbance level increased (clip – light burn – moderate burn – heavy burn), cover of non desirable grass also increased. However, only the heavy burn treatment resulted in a significant increase in non desirable grass cover ($p < 0.01$, p.adj = < 0.05).

As with native grass species, all disturbance treatments allowed for an increase in cover from pre-disturbance to postburn as no native species were present prior to disturbance. Post hoc pairwise analysis resulted in only the moderate burn treatment significantly increasing cover ($p < 0.001$, p.adj = 0.01).

Ruderal herb species significantly increased in cover post disturbance treatment but was only found to be significant within the light burning treatment ($p < 0.001$, p.adj = 0.01). Both forbs and legumes failed to result in any significant increases from pre-disturbance to seven months postburn. These results still are significant in the sense that new native species and legumes were able to colonize post disturbance and increase site diversity and functional plant group diversity.

Table 4-3. ANOVA to determine significance of disturbance treatment and timing effect on percent cover of plant functional groups for mesocosm units.

Model:	**% Cover Non-Desirable = Disturbance Treatment (Fixed) + Timing (Fixed) + Turf ID (Error)**				
Effect					
	Sum-of-squares	Mean squares	df	F-Value	p
Disturbance Treatment * Timing	1886.50	471.630	4	1.733	0.174
Disturbance Treatment	303.810	75.950	4	0.279	0.888
Timing	2281.670	2281.670	1	8.386	**<0.001**

Model:	**% Cover Native Grass = Disturbance Treatment (Fixed) + Timing (Fixed) + Turf ID (Error)**				
Effect					
	Sum-of-squares	Mean squares	df	F-Value	p
Disturbance Treatment * Timing	143.830	35.958	4	0.912	0.464
Disturbance Treatment	143.830	35.958	4	0.912	0.464
Timing	201.670	201.667	1	5.115	**<0.05**

Model:	**% Cover Ruderal Herbs = Disturbance Treatment (Fixed) + Timing (Fixed) + Turf ID (Error)**				
Effect					
	Sum-of-squares	Mean squares	df	F-Value	p
Disturbance Treatment * Timing	454.170	113.540	4	1.986	0.127
Disturbance Treatment	461.560	115.390	4	2.0188	0.122
Timing	770.420	770.420	1	13.479	**<0.001**

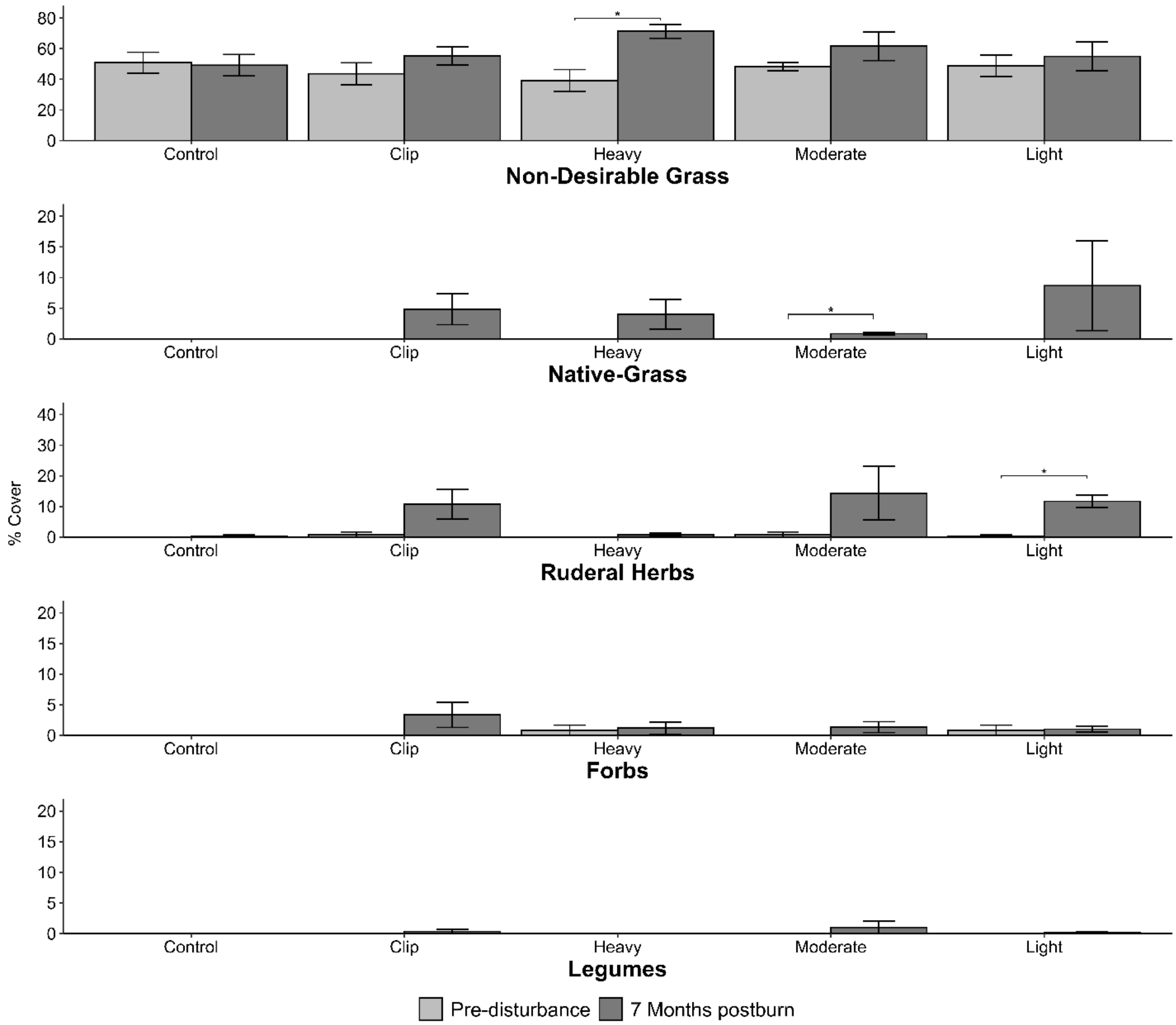

Figure 4.8. Percent cover of five plant functional groups across disturbance treatment and timing for pre-disturbance and 7-months postburn in a mesocosm fire experiment (n = 6 within each group, +/- 1 SE). Pairwise comparisons within treatment groups were completed and adjusted with BH corrections. '*' $p < 0.05$, non-significant values were not plotted.

Examining plant community assemblage by species comparing pre-disturbance to seven months postburn, it is evident that postburn conditions allowed for a significant increase in ruderal herb species, along with seeded native grasses, legumes, and forbs as these species were not observed in the community prior to disturbance (Figure 4.9). Two notable non desirable grass species: *Elymus trachycaulus* and *Bromus inermis* resulted in an increase in cover from pre-disturbance (40 & 3 %) to postburn (44 & 6%) respectively. This increase in cover is confirmed in ANPP results shown below (Figure 4.9).

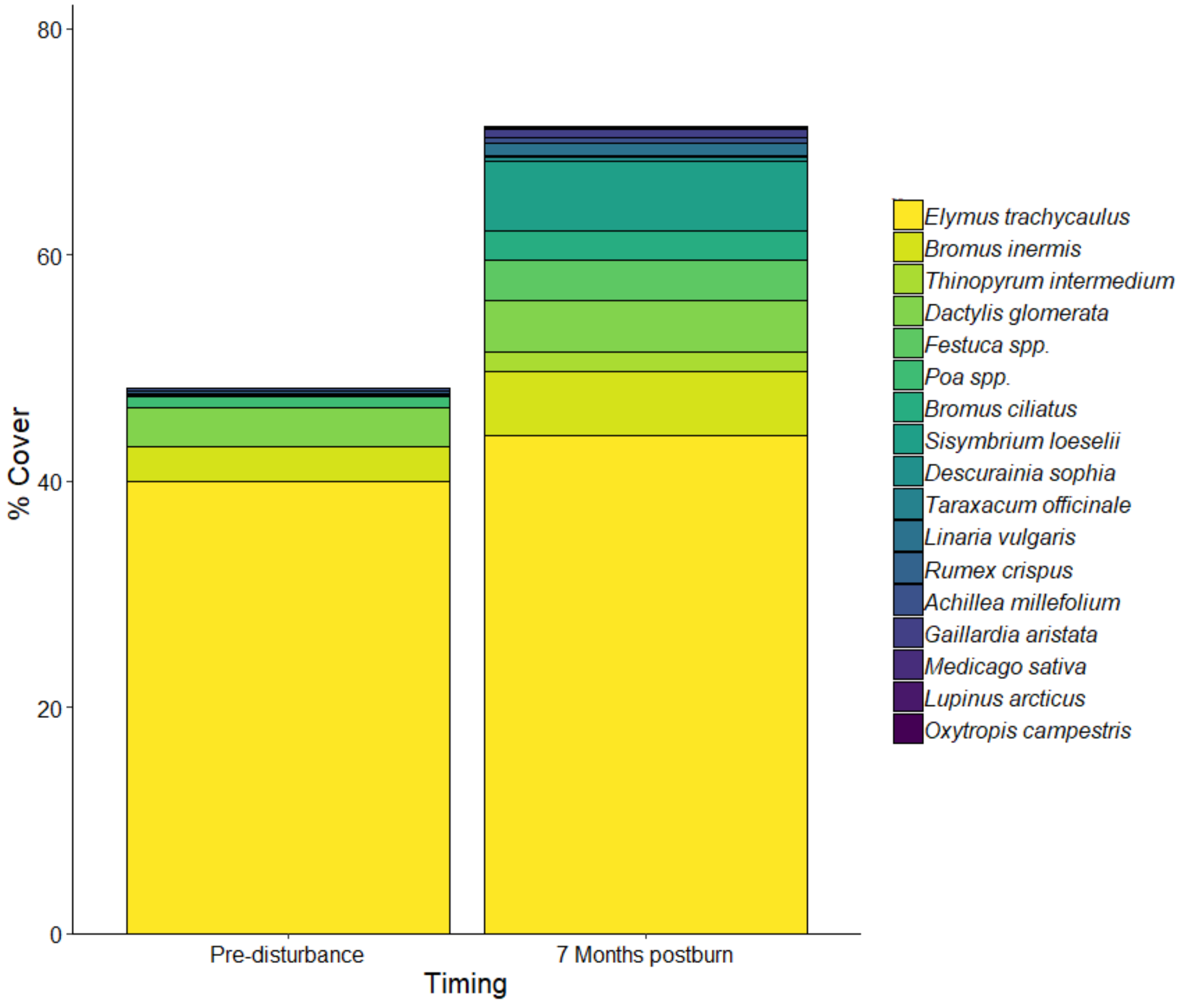

Figure 4.9. Mean percent plant cover by species across all experimental mesocosm units by timing of pre-disturbance to project completion at seven-months post burn. Control plots were not considered in the postburn category here (n Pre-disturbance = 30, n 7 Months postburn = 24).

Aboveground Net Primary Productivity

The interaction term (between disturbance and timing) in our model showed a significant effect on normalized ANPP (F = 11.3225, p <0.001, Table 4-4). Additionally, disturbance treatment alone represented no significant effect, while timing (pre-disturbance & 7-months postburn) show a slight but non-significant effect (F = 3.9811, p = 0.09, Table 4-4). Pairwise comparisons within treatment groups across treatment and timing were completed to determine where the significant differences were (Figure 4.10).

Table 4-4. ANOVA to determine significance of disturbance treatment and timing on normalized ANPP for mesocosm units.

Model:	**Normalized ANPP = Disturbance Treatment (Fixed) * Timing (Fixed) + Turf ID (Error)**				
Effect					
	Sum-of-squares	Mean squares	df	F-Value	p
Disturbance Treatment * Timing	0.621	0.207	3	11.322	**<0.001**
Disturbance Treatment	0.050	0.016	3	0.926	0.445
Timing	0.054	0.054	1	2.981	0.099

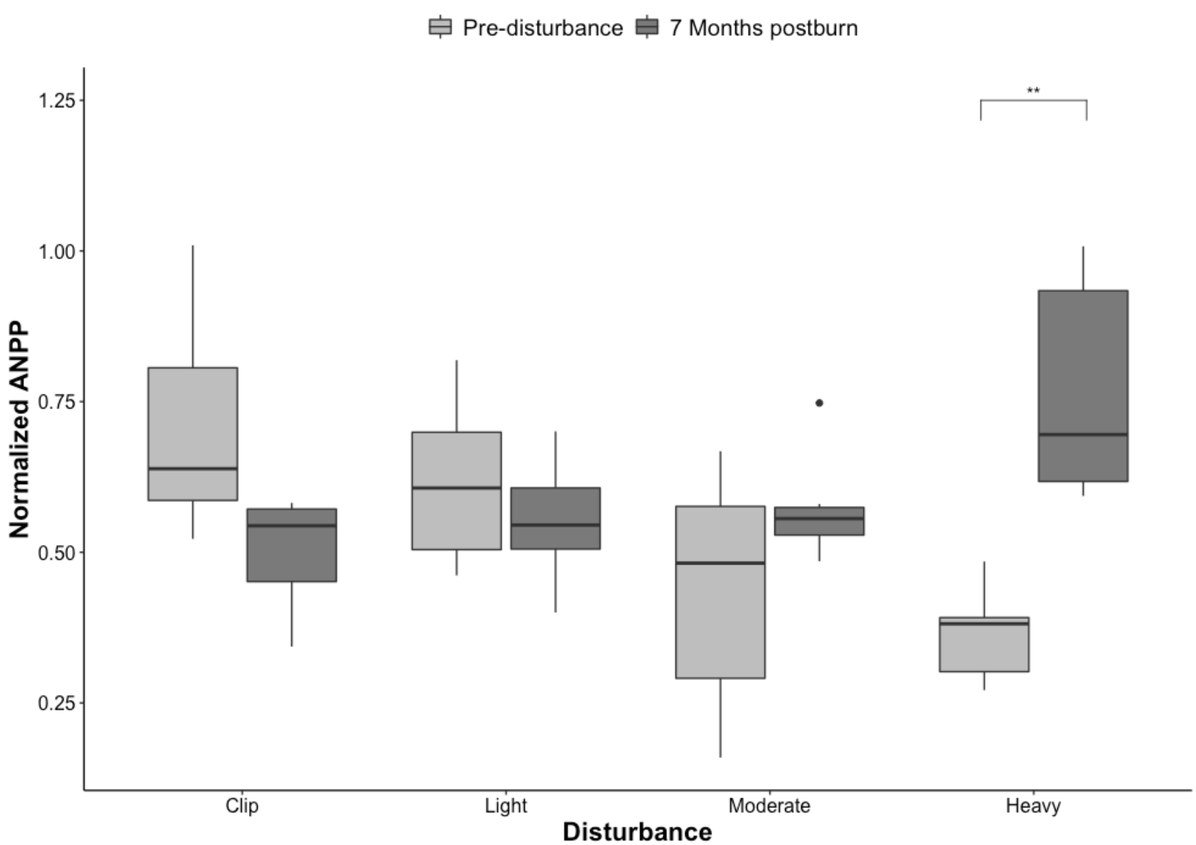

Figure 4.10. Aboveground net primary productivity (ANPP) normalized against its paired control by timing in pre-disturbance and 7-month postburn across disturbance treatments from each mesocosm unit (n = 6 for each group). Pairwise comparisons were completed within treatments between pre-disturbance, and final post burn conditions and p-values were adjusted with BH corrections.

Pairwise comparisons between disturbance treatments and timing show significantly greater normalized ANPP from pre-disturbance to seven-month postburn conditions when the experiment was completed (Figure 4.10). Significant differences were found within the heavy burn treatment (n = 6, p = <0.01 p.adj = <0.001). Clipping treatment was found to be significantly different prior to p-value adjustment (n = 6, p = <0.05, p.adj = 0.08) and approaches significance after adjustment. These results suggest that light disturbance such as clipping and light burning decreases ANPP whereas increasing intensity of disturbance results in increased ANPP (Figure 4.10).

Fire Disturbance, ANPP & Litter Relationship

There was no significant relationship between litter mass and ANPP in pre-disturbance (ANPP Normalized = 0.58 – 0.032 x litter mass, Adjusted R^2 = -0.02, p = > 0.05) and a significantly negative relationship after burning within the 7-month postburn period (ANPP Normalized = 0.76 – 0.46 x litter mass, Adjusted R^2 = 0.15 , p = < 0.05) suggesting a negative effect of litter on ANPP. Pre-disturbance metrics also represent a larger amount of variance with litter appearing to limit ANPP while disturbance generally appears to increase ANPP (Figure 4.11).

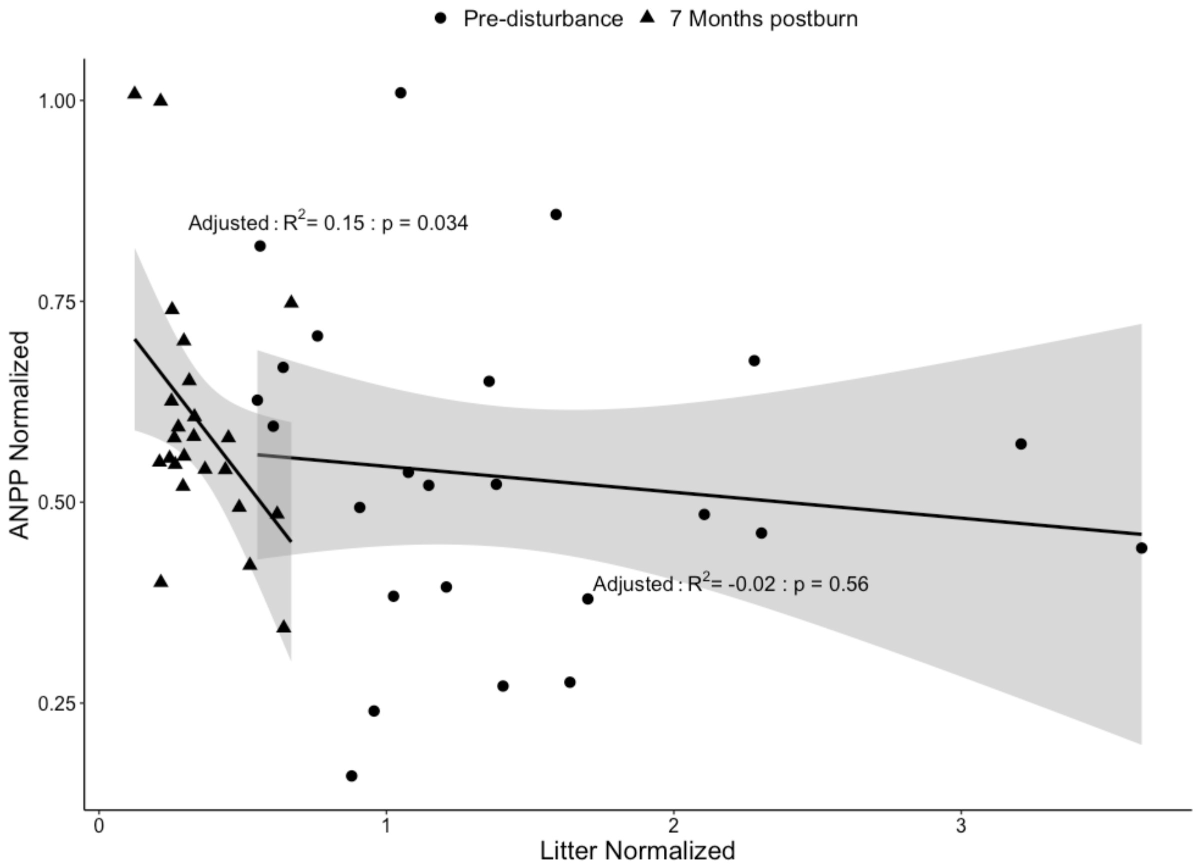

Figure 4.11. Relationship between normalized aboveground net primary productivity (ANPP) and litter mass for a seven-month mesocosm experiment. Pre-disturbance: ANPP Normalized = 0.58 – 0.032 x litter mass, Adjusted R^2 = -0.02, p = > 0.05, 7-month postburn: ANPP Normalized = 0.76 – 0.46 x litter mass, Adjusted R^2 = 0.15 , p = < 0.05.

Disturbance, Diversity & Litter Relationship

To examine the relationship between diversity and litter, linear regression was conducted examining Shannon-diversity, Simpsons Index, and species richness against litter biomass. There was a significant negative relationship between among all diversity measures against litter biomass from pre-disturbance to project completion at seven-months postburn (Shannon-diversity, Adjusted R^2 = 0.11, p = 0.007, Simpson-index, Adjusted R^2 = 0.12, p = 0.03, Species richness, Adjusted R^2 = 0.13, p = 0.03). Only Shannon-diversity was plotted for visual representation (Figure 4.12). This relationship reiterates the negative effect of litter on the plant community, as it appears to limit plant diversity.

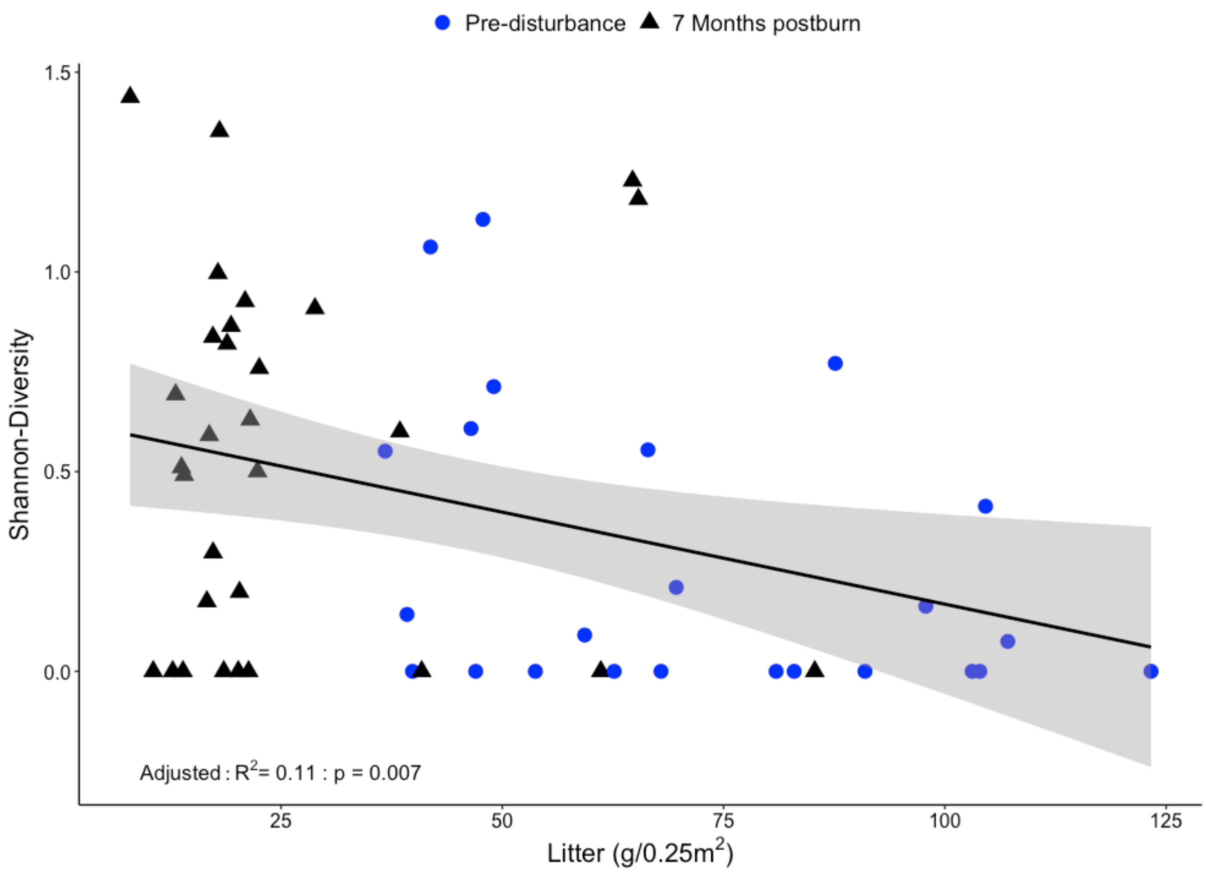

Figure 4.12. Relationship between Shannon-Diversity and normalized litter mass for a seven-month mesocosm experiment (Adjusted R^2 = 0.11, p = 0.007) .

Plant Community Analysis

The response of the plant community to disturbance treatment and timing was further investigated with a permutational multivariate analysis of variance which revealed that community structure based on Bray-Curtis dissimilarities was significantly different between plots ($p<0.001$, Table 4-5).

Generally, all disturbance treatments and timing appear to have resulted in a significant shift in the community structure ($p<0.001$, Figure 4.13. , Table 4-5). Plant community response to timing based on Bray-Curtis dissimilarities was also found to be significant ($p<0.001$, Figure 4.13, Table 4-5).

Table 4-5. PERMANOVA testing community structure based on the effect of disturbance treatment (clip, control, and all burn treatments lumped together) and timing (pre-disturbance, and all postburn timings lumped together) for mesocosm turves extracted from Highmont Tailings, Highland Valley Copper mine.

Source of Variation	*df*	F	p
Disturbance Treatment	4	9.07	**0.001**
Timing	4	9.26	**0.001**
Disturbance Treatment*Timing	16	0.88	0.727
Residuals	125		
Total	149		

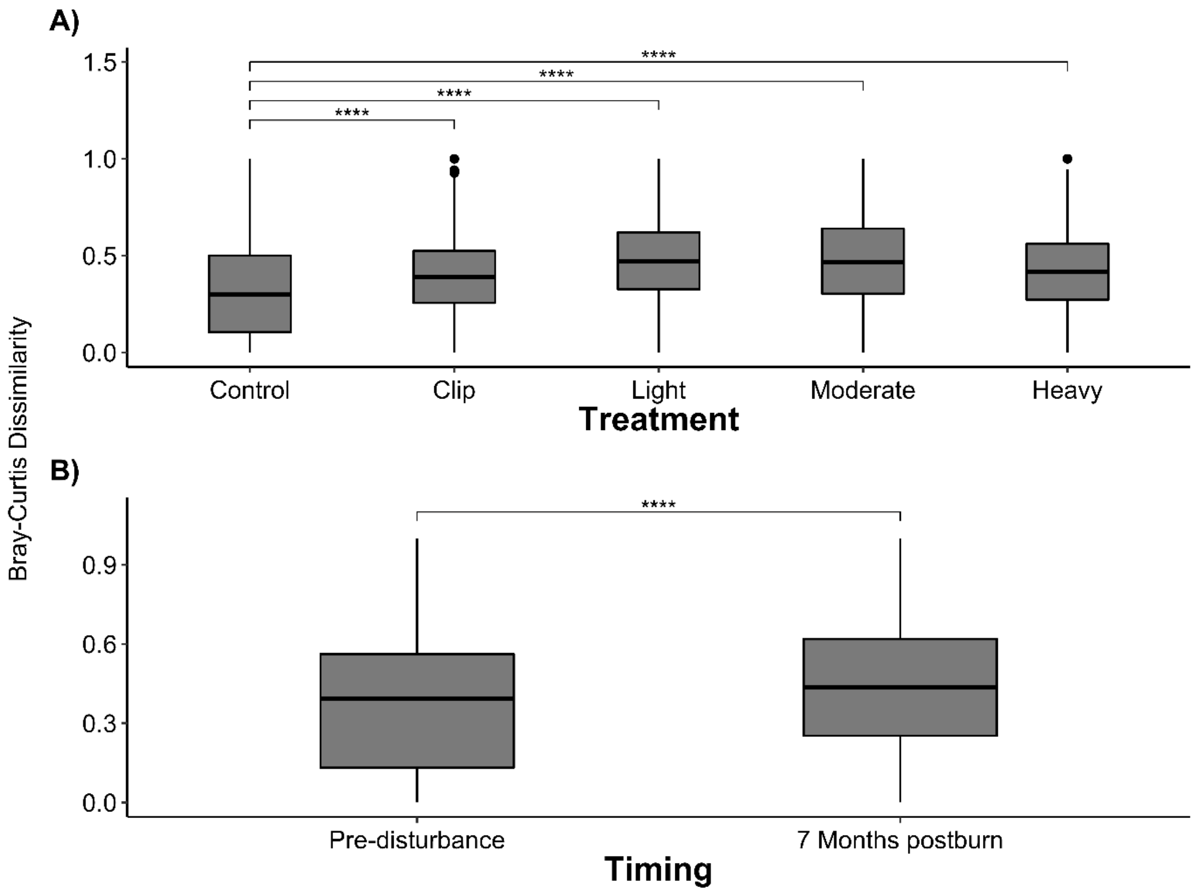

Figure 4.13. Extracted Bray-Curtis Dissimilarity distance plotted by A) Disturbance Treatment (seven-months postburn, light, moderate, and heavy refer to burn intensity) and B) Timing for field mesocosm units extracted from HVC, Highmont Tailings. 7 Months postburn pools all treatment plots excluding the control and Pre-disturbance pools all treatments.

Soil Elemental Analysis

Soil level and timing (pre disturbance vs. 7-month post disturbance) significantly affected nitrogen and carbon concentrations, where as the interaction of disturbance treatment and timing were found to significantly effect the C:N ratio (Table 4-6). Direct comparisons of major elements by soil level depth were not directly of interest and therefore not pursued. Pairwise comparison post-hoc analysis was completed to determine the pairings of significant differences.

Table 4-6. ANOVA to determine significance of disturbance treatment, timing, and level on total nitrogen concentrations for mesocosm units.

Model:	**Total N = Disturbance Treatment (Fixed) + Timing (Fixed) + Level (Fixed) + Turf ID (Error)**				
Effect					
	Sum-of-squares	Mean squares	df	F-Value	p
Disturbance Treatment	0.101	0.025	4	1.434	0.252
Level	1.170	1.170	1	66.072	**<0.001**
Timing	0.237	0.237	1	13.399	**<0.001**

Model:	**Total C = Disturbance Treatment (Fixed) + Timing (Fixed) + Level (Fixed) + Turf ID (Error)**				
Effect					
	Sum-of-squares	Mean squares	df	F-Value	p
Disturbance Treatment	7.957	1.989	4	1.049	0.401
Level	125.353	125.353	1	66.141	**<0.001**
Timing	22.460	22.460	1	11.850	**<0.001**

Model:	**C:N = Disturbance Treatment (Fixed) * Timing (Fixed) + Level (Fixed) + Turf ID (Error)**				
Effect					
	Sum-of-squares	Mean squares	df	F-Value	p
Disturbance Treatment * Timing	109.632	27.407	4	4.190	**<0.01**
Disturbance Treatment	9.739	2.434	4	0.372	0.826
Level	14.023	14.023	1	2.144	0.146
Timing	3.512	3.511	1	0.537	0.465

Pairwise comparisons between disturbance treatments and timing show significantly greater nitrogen concentrations from pre-disturbance to seven-month postburn conditions when the experiment was completed (Figure 4.14). Pairwise comparisons highlighted light ($n = 6$, $p = <0.01$ $p.adj = 0.02$) and heavy burn ($n = 6$, $p = <0.01$, $p.adj = 0.02$) treatments as increasing total nitrogen content within the top 10 cm of the soil. A similar trend was observed upon analyzing total carbon, such that significantly greater carbon was observed within light ($n = 6$, $p = <0.01$, $p.adj = 0.01$) and heavy ($n = 6$, $p = <0.01$, $p.adj = 0.01$) post burn conditions when compared to pre-disturbance. Comparisons of C:N ratio were found to be significantly different prior to p-value adjustment within the clipping treatment ($n = 6$, $p = 0.01$, $p.adj = 0.06$) and approaches significance after adjustment but fails to meet α 0.05.

Generally, concentrations of total nitrogen and total carbon were found to be greater within the top 10cm of soil after disturbance treatment. Additionally, the C:N ratio remained generally stable likely due to both nitrogen and carbon increasing together.

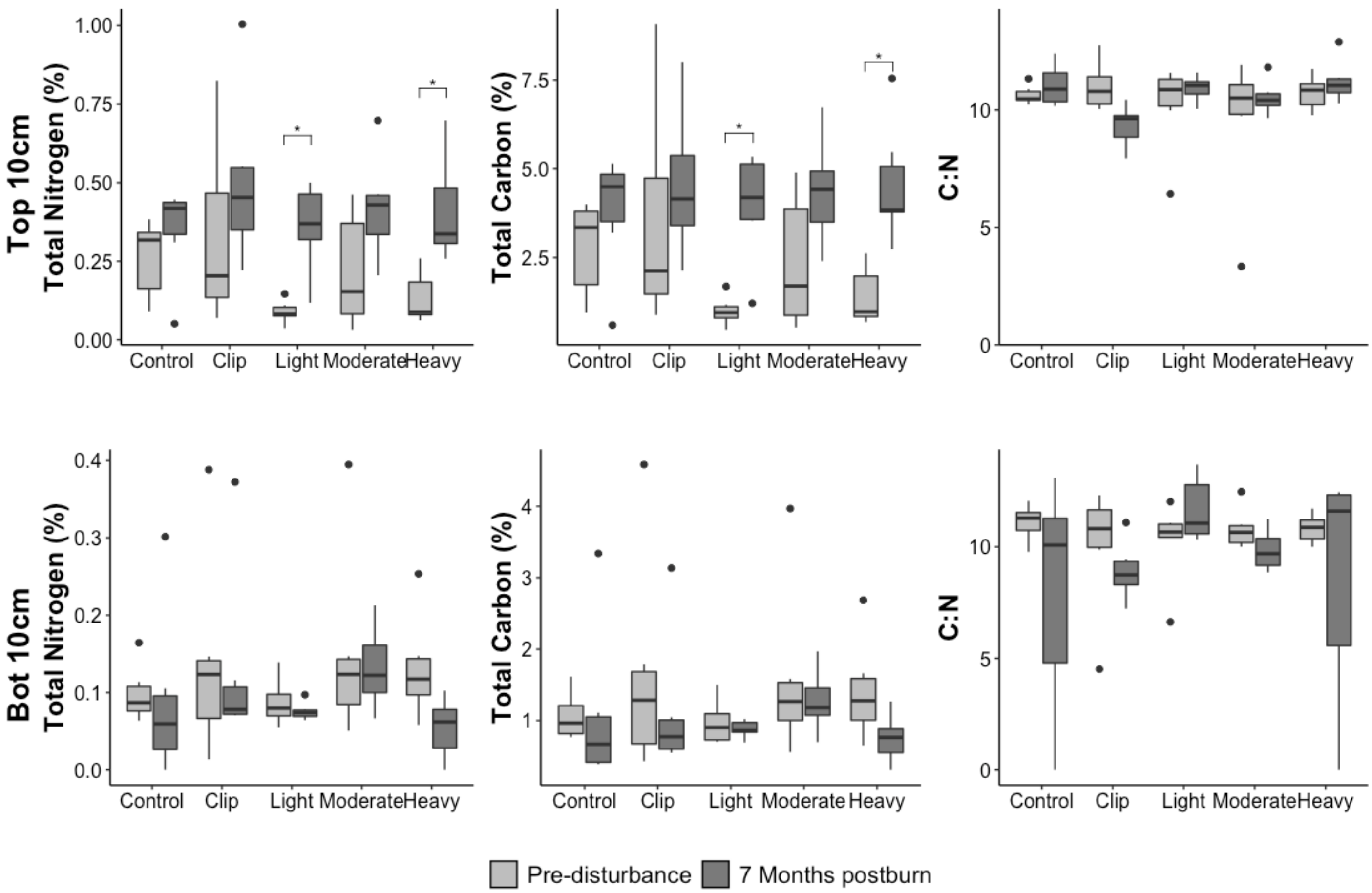

Figure 4.14. Total nitrogen, carbon, and carbon to nitrogen (C:N) ratio separated by top 10 cm and bottom 10 cm of soil sample extracted from each mesocosm unit (n = 6 for each group). Pairwise comparisons were completed within treatments between pre-disturbance, and final post burn conditions and p-values were adjusted using BH corrections. * = 0.05, ** = 0.01, *** = 0.001, **** = 0.0001. (Bot & Top 10 cm = bottom or top 10 cm of sample extracted from a 30 cm soil core pulled from each mesocosm unit).

Pairwise comparisons across total nitrogen, carbon, and C:N ratio for bottom 10 cm of soil were all insignificant with no apparent trend or affect occurring across treatment types.

pH

A total of three pairwise comparisons were made within each treatment for a total of fifteen tests. Each comparison examined median pH across pre-disturbance, three-months postburn, and seven-months postburn (Table 4-7). The range of average soil pH in pre-disturbance conditions was 6.56 – 7.16, while the median range was 6.55 – 7.09. After fire disturbance, the light burning treatment resulted in a significant average and median pH to a value of 7.25 for both values ($p<0.01$, Figure 4.15). Both heavy and clip disturbance also resulted in significant differences in median pH in comparing three-month postburn to seven-month postburn. Although significantly different, the median pH change appears to be an increasing trend within the control, regardless of any disturbance treatment (Figure 4.15). Interestingly, the light burn treatment had a decrease in pH from 7.16 at pre-disturbance to 6.79 three-month post burn, in addition to the heavy burn treatment which resulted in a small pH decline from 6.83 to 6.71.

Table 4-7. ANOVA to determine significance of pH across disturbance treatment and timing within mesocosm units

Model:	**pH = Disturbance Treatment (Fixed) * Timing (Fixed) + Turf ID (Error)**				
Effect					
	Sum-of-squares	Mean squares	df	F-Value	p
Disturbance Treatment	0.398	0.099	4	2.006	1.24E-01
Timing	2.175	1.087	2	21.907	**1.47E-07**
Disturbance Treatment * Timing	0.776	0.097	8	1.954	7.22E-02

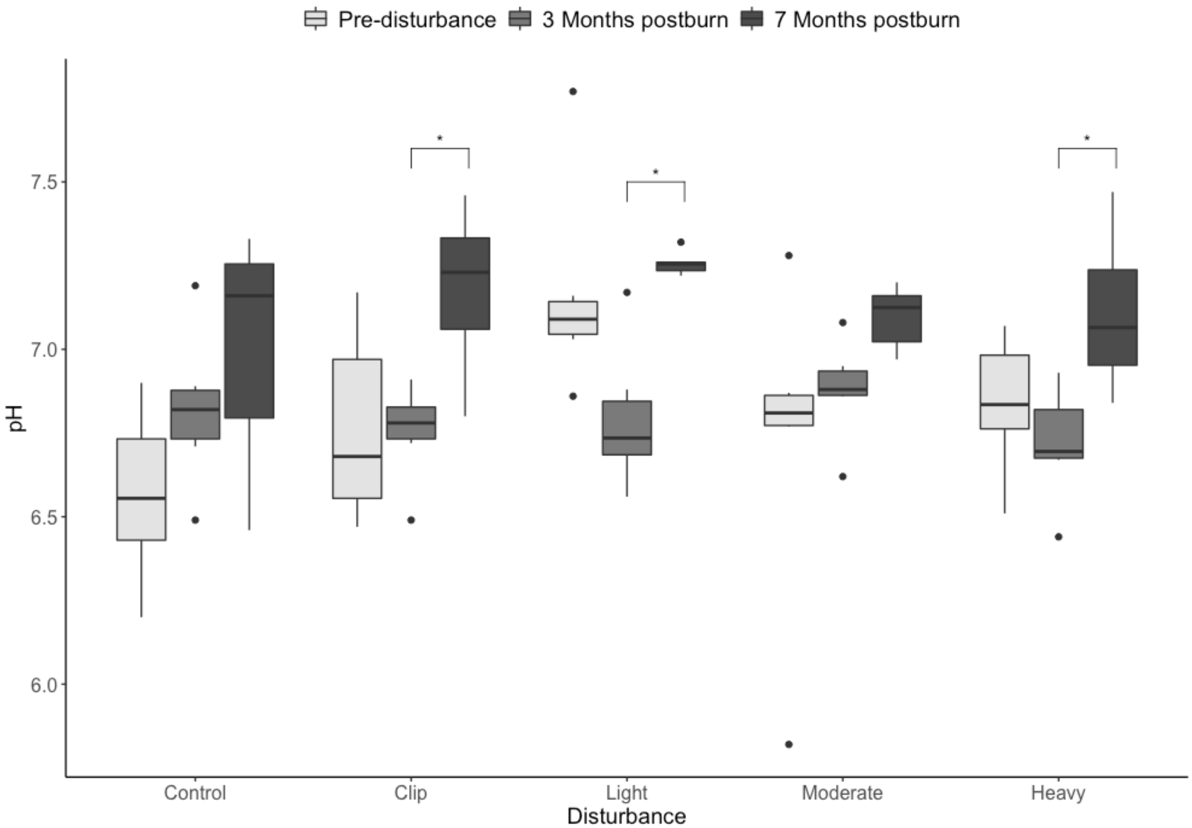

Figure 4.15. pH of the top 10 cm of soil extracted from each mesocosm unit (n = 6 for each group). Pairwise comparisons were completed within treatments between pre-disturbance, three-months postburn and 7-months postburn and p-values were adjusted using BH corrections. * = 0.05, ** = 0.01, *** = 0.001, **** = 0.0001.

DISCUSSION

Impacts of Disturbance on Diversity and the Plant Community

Disturbance treatment regardless of severity resulted in an increase in species richness, evenness, and diversity when compared to the control. Light burn, moderate burn, and clipping disturbance all appear to be synonymous with one another with respect to relative increases in diversity metrics while heavy burning resulted in the lowest response across treatments. Furthermore, it appears as though the light and moderate fire disturbance were not fully distinguishable from one another such that a similar response was observed within each treatment.

The moderate and light burn response found within this experiment slightly coincides with the generally accepted “hump-backed-model” (HMB), which states the greatest diversity occurs in the moderate or middle range of a physical gradient of plant productivity or disturbance (Grime 1973, Fraser et al. 2015). A similar result was also found within the field in more recent work by Ashouri et al. (2016) and Heydari et al. (2017) whereby maximum values for richness corresponded to sites with moderate stress that were characterized from high to low based on fire disturbance and grazing.

In examining disturbance treatment with timing effect together we can better understand how the plant community responded. A slightly hump-backed distribution between disturbance treatment and time was observed. Initially, when disturbance treatment is applied, and the community was observed one to three months post burning, diversity metrics approach their maximum values, while diversity decreased and stabilized near the end of the experiment at seven months. This initial increase and maximum value in diversity and evenness was likely due to highly favorable conditions post-burn which aided in the germination of the seeded native species. However, as the experiment proceeded, the dominant non-desirable rhizomatous grasses began to expand both above and belowground, depositing a layer of litter on the ground surface and thereby outcompeting new seedlings for space, and resources (Facelli and Pickett 1991, Scheintaub et al. 2009). A similar response was found by Kirkman et al. (2014) where dominance of a rhizomatous grass was thought to be a factor facilitating community dominance after prescribed burning. This relationship was further exemplified within the heavy disturbance treatment as diversity measures across treatments were lowest (Figure 4.7 D), but ANPP after disturbance was highest (Figure 4.10).

Early successional species that were able to withstand competition, contributed significantly more to the increase in biodiversity over time. Although competition was not directly measured, observationally this result aligns with the post-fire stages and benefits of postfire conditions. The first stage represents a ‘race to occupy the area’ when there is little competition for resources (light, water, space, etc.). Secondly, as growth continues resources become progressively more important, and represents ‘the effort to maintain space’(Ghermandi et al. 2004, Scheintaub et al. 2009).

The impacts of disturbance treatment and timing were also analyzed for community-level divergence. Both timing and disturbance treatment resulted in significant changes to the plant community. This divergence is likely due to the similar composition of well-established non desirable grass species across experimental units, being contrasted by the later established native species that responded differently to disturbance treatments and other environmental gradients (Matthews and Spyreas 2010). When examining divergence over the experimental period with respect to timing, we find significant community change away from the pre-disturbance community likely due to the increased number of new native species over time from seeding and new ruderal species appearing due to fire disturbance (Figure 4.8 & 4.13B).

Total Cover and Plant Functional Group Response to Disturbance

All disturbance treatments resulted in a differential response among the plants treated within each mesocosm experimental unit. In all experimental units the former species found in pre-disturbance observations were observed seven-months post disturbance (Figure 4.9). The community shift seven-months post was still largely dominated by non-desirable grasses but also resulted in the establishment of opportunistic ruderal herbs and native seeded species that took advantage of the secondary succession. This response is consistent with an appearance of a ‘fugitive’ community after disturbances which colonize early from the seedbank, which in this case was represented by ruderal herb species (Ghermandi et al. 2004).

All plant functional groups studied responded to disturbance such that cover increased after disturbance (Figure 4.8). This increase is to be expected in consideration of the native seeded species but more importantly we should consider how disturbance affected the non-desirable grasses. The increase in cover for non-desirable grass species remains consistent with similar studies that have shown burning to increase cover in tall grass species (Towne and Owensby 1984, Peterson and Reich 2008, Kirkman et al. 2014). This increase in cover of non-desirable grass species is likely a factor of rhizomatous spread. This spread and increase in cover then can facilitate continued dominance and exclusion of other species due to their strong ability to increase in size via vegetative spread, while occupying the canopy increases its competitive advantage to native bunchgrass species (Peterson and Reich 2008, Gough et al. 2012). Augustine et al. (2014) and Collins and Calabrese (2012) examined burning in a semiarid grassland and tallgrass prairie and found that C_3 grass production was reduced in burn treatments, while C_4 grass production remained unaffected by burn treatments and increased in tallgrass prairies. The results from this study, however, indicate that burning treatments did not significantly reduce the cover or ANPP of non-desirable grass species occupying the mine site.

Seeded native grasses and forbs performed the best with respect to establishment on postfire conditions and should continue to change the trajectory of the site towards more native species colonization through natural reseeding events. A small change in forb cover was observed in burn treatments, however a larger response was observed within the clipping treatment. I cannot say for certain that fire disturbance alone results in increased forb cover, due to the significant increase observed within the clip treatment, however this result remains consistent with other studies observing forb increases post fire disturbance (Ruthven et al. 2000, Goergen and Chambers 2009, Scheintaub et al. 2009).

Impacts of Disturbance on Aboveground Net Primary Productivity

The impact of disturbance on ANPP was found to remain negative to neutral with respect to light disturbance, while productivity appeared to increase as severity increased from moderate to heavy burning. The light – moderate disturbance fire observation remains consistent with investigation of productivity effects of fire on Mediterranean type grasslands (Hervey 1949, Henry et al. 2006) and more recent work completed within a semi-arid shortgrass steppe (Scheintaub et al. 2009). The net neutral to negative response to productivity may be more of an effect of timing of the burn with respect to whether the grass species are physiologically active or dormant. Scheintaub et al. (2009) found that the consumption of live tissue may have negatively impacted plants more than dormant season fire.

The significant increase in ANPP found within the heavy burn treatment is more consistent with findings of burning completed in tallgrass prairie by (Briggs and Knapp 1995, Turner et al. 1997) that found ANPP across burned plots was significantly higher than unburned plots and was correlated to soil moisture and removal of litter. The relationship of ANPP to litter however was not found within this study as a very weak relationship was found (Figure 4.10). In a semi-arid environment, this relationship suggests that litter in this case does not inhibit ANPP and perhaps may even increase water retention by decreasing evaporative loss (Scheintaub et al. 2009). Given the large variation within the heavy treatment, the relationship is still believed to be net neutral to negative which remains consistent with other studies.

The general theory that terrestrial ecosystem production is limited by N availability, to a point where productivity inhibits diversity is supported in this case and reflects the community response to disturbance we have observed thus far (Potts et al. 2012). The observed increase in total N (Figure 4.14), only reflects a minor to neutral change in productivity (Figure 4.10), but increased cover of non-desirable grass species (Figure 4.8) resulting in higher competitive exclusion to other species through resource competition with greater N uptake, resulting in shading through increased cover. The plant response to disturbance that resulted in consumption of litter is more suggestive of a significant contributor to increase site diversity as control treatments across the board resulted in lower diversity, evenness, richness, and had a lower species composition.

Litter Dynamics in the Plant Community

Significant interactions were found between the dynamics of plant litter and its effects on the plant community productivity (ANPP), and diversity. A significant negative relationship was found between ANPP and litter, such that productivity decreased sharply with higher levels of litter (Figure 4.11). Additionally, the relationship between diversity and litter was examined and a similar effect was found such that plant community diversity was maximized when litter was removed by disturbance (Figure 4.12). This response can be attributed by site productivity overall, in addition to the species found within the environment that contribute to litter deposition. Litter alters the physical and chemical environment directly and indirectly through release of nutrients in breakdown, intercepting light, shading seeds and seedlings, and reducing soil temperature (Facelli and Pickett 1991, Scheintaub et al. 2009). Rhizomatous spread by the non-desirable grass species are a significant factor in facilitating continued dominance within the community and exclusion of other species through competitive exclusion of the resources listed above (Kirkman et al. 2014). This result remains concurrent with other studies that have found when accumulated litter is not periodically removed by grazing or fire disturbance, productivity, and plant diversity decline (Anderson 1990, Collins and Calabrese 2012).

Soil Elemental Analysis & pH Response to Fire

Elemental analysis results of the experiment indicate that there was an overall increase in total nitrogen and carbon across treatments within the top 10 cm of soil while the bottom 10 cm resulted in no significant change. With respect to the top 10 cm, it appears that disturbance treatment resulted in a larger total increase of N and C into the system which was likely an influence of soil nutrient addition by ash from burning. The increase in nitrogen by clipping is harder to explain however, as a similar study conducted by Marion et al. 1991 found no significant increases across clipping treatments. Soil nitrogen increases from burning are however consistent with other studies whereby the availability of soil inorganic N (NH_4 , NO_3) was found to increase in response to fire (Marion et al. 1991, Covington and Sackett 1992, Rau et al. 2008, Augustine et al. 2014). Commonly, NH_4 increases are directly correlated with biomass consumption (Covington and Sackett 1992).

Loss of nutrients through burning also commonly is in question when conducting prescribed burning. However, the highest temperature achieved during prescribed burning was approximately 343°C and evidently provided no total nitrogen losses through volatilization. Nutrient loss through volatilization is largely dependent upon fuel load, efficiency of combustion and resulting temperature. Major soil nutrients such as N , K and P, become volatile at 200°, 760°, and 774°C respectively (Rau et al. 2007). With respect to the slight decrease in C:N ratio across disturbance treatments this could be attributed to rapid mineralization and release of the increased inorganic N, resulting in the slight increased cover of non-desirable grass observed in previous results and other studies (Figure 4.8) (Enwezor 1976, Fujimaki et al. 2009, Biswas and Micallef 2019).

Soil pH increased significantly over the course of the experiment as observed within all treatments. The resultant increase in pH due to fire disturbance is common and has been reported in both field and laboratory experiments (Ubeda et al. 2005, Scharenbroch et al. 2012). This is likely the result of increased availability of cations and organic acid denaturation occurring during burning (Ubeda et al. 2005). In this experiment however it appears something else is occurring to result in increased pH over time regardless of disturbance. Possible explanation of this could be heavy metal leaching or oxidization of minerals occurring through watering events, resulting in pH increases as these metals accumulate in the experimental units.

CONCLUSION

The results of this study show diversity enhancements towards shifting the plant community composition from a non-desirable grass dominated grassland community to a native grassland. Disturbance by burning or clipping had a significant influence on plant community response whereby clipping in this case was similar to moderate disturbance burning resulting in agreement with the “hump-backed-model”. Due to the currently well-established state of the dominant grasses within the mesocosm units, disturbance paired with seeding is recommended as a tool to enhance the diversity of the site to aid in shifting the ecosystem towards a native grassland as new species were only observed in disturbed treatments. Plant community composition shifted as a result of disturbance. Native species establishment although minimal is projected to continue to change the trajectory of the mesocosm units over time towards a native grassland. Further research should consider distinguishing between fire severity effects through greater detail to disentangle clipping effects from fire disturbance while also implementing a severe fire treatment. Additionally, watering events and leachate from mesocosm units should be tracked to examine soil characteristic changes over time with respect to plant response to water and productivity.

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Chapter 5 : Research Implications, Conclusions & Appendices

As disturbances to our ecosystems continue to occur through the extraction of resources, it is of necessity that we are able to restore and reclaim ecosystem function to disturbed lands. My research provides an approach that implemented contemporary knowledge of disturbance ecology with traditional Indigenous knowledge of prescribed burning to enhance ecosystem recovery on disturbed mine sites.

Utilizing prescribed burning as a method to enhance and accelerate ecosystem recovery within a disturbed mine tailings facility found varying success. In a field setting that comprised a grassland ecosystem that in its present state is dominated by largely undesirable, agronomic, highly productive, rhizomatous grasses, a single disturbance event is not likely to transition the ecosystem towards a native grassland. However, evidence was found that resulted in increased plant diversity, and forb productivity with limited success (Scheintaub et al. 2009). It is likely that without a continued disturbance of some kind, the ecosystem will return to its preburn, low diversity state. Similar results were gathered in a greenhouse setting whereby the pre-disturbance plant community continued to dominate, however a more significant shift occurred in the plant community that allowed for increased diversity under controlled conditions and a larger percentage of native species to germinate and take hold in the community. I suggest that the disparity between the observed effects of prescribed burning in the field resulting in a reduced level of species diversity in comparison to the greenhouse trial hinges largely upon requirements for seedling germination. In the greenhouse, unlike the field, seedlings were watered resulting in better germination. I speculate that this boost is a major contributor towards the seeded species being able to withstand the fast growth response of the agronomics postburn which allowed a larger window in which the seedlings could remain in the fight for resources. I were also able to elucidate a significant factor that is likely responsible for limiting the plant community. Plant litter was found to significantly limit the diversity of the plant community as diversity decreased with increasing amounts of plant litter deposited by the fast-growing agronomic species (Foster and Gross 1998).

From this study it is clear that disturbance has a role to play in changing the trajectory of the plant community. It is also clear that the plant community at HVC, Highmont Tailings, is being limited by a combination of highly productive agronomic grasses and their subsequent litter deposition.

As the desire to complete this project was largely spearheaded by the Nlaka'pamux nation, this project can be seen as a success such that western scientific and traditional Indigenous knowledge was considered in efforts towards a common goal of enhancing biodiversity on a previously reclaimed site. This type of partnership is unique with respect to collaborating on mine reclamation goals and is gaining positive momentum towards starting a dialogue to creating a mutual industry/ Indigenous relationship. Indigenous perspectives and consideration of Indigenous Methodologies can and should be further developed in future projects.

Considerations for future research should focus on a more precise, replicable application of fire disturbance within a field setting. In addition to this, teasing out the effects of fire severity should continue to be examined as it is clear there is a role to be played with respect to varying plant community response. Finally, any future projects that aim to create a relationship with Indigenous communities should pay respect to Indigenous ways of knowing and focus on integrating Indigenous Methodologies. These relationships should focus on ways to collaborate to extend modern scientific practice that respects both ways of understanding.

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Appendix A: Semi-Structured Interview Guide

Q1: Can you describe your job title, responsibilities, and history working with Highland Valley Copper?

Follow up: How did you first get involved in what you do and what inspires you to do your work?

Q2: In your opinion, what responsibility if any, do we have in restoring or reclaiming ecosystems and landscapes on disturbed land?

Follow up: How would you describe Highland Valley Coppers approach to restoration and reclamation efforts?

Q3: To you, what role does community engagement, social responsibility, and maintaining relationships with key stakeholders play in the mining industry and who would you list as some the key stakeholders?

Q4: What sort of relationships does Highland Valley Copper have with important stakeholders of the area and can you describe those relationships?

Follow up: From the prescribed burning project, I understand that Teck Highland Valley Copper has a relationship with the Nlaka'pamux people. How did this relationship come about?

Follow up: Can you describe the process by which the prescribed fire project came to be?

Follow up: How active are you in managing and facilitating this relationship and can you describe your experience with this? What does this process look like?

Follow up: What are some of the challenges or opportunities, that you see in these relationships and incorporating multiple viewpoints?

Follow up: In the field of restoration and reclamation what role does traditional ecological knowledge play?

Follow up: What strategies do you use to maintain good relations with the Nlaka'pamux?

Q5: Aside from this project, can you describe some ways, if any, that the local community and Indigenous collaboration are incorporated into the operations at Highland Valley Copper?

Follow up: Can you describe the relationship between Highland Valley Copper and the Nlaka'pamux in terms of what the expectations of both parties are when working together?

Follow up: Outside of providing the rationale based on traditional ecological knowledge for prescribed burning, can you describe the role the Nlaka'pamux played as part of completing the prescribed burning project?

Follow up: What sort of feedback, if any, have you received from the Nlaka'pamux on these projects? What does this relationship look like after project completion?

Q6: Can you describe the extent or scale to which Nlaka'pamux consultation and collaboration is involved in other operations within Highland Valley Copper?

Follow up: Can you describe what the consultation may look like? I understand your company ran and conducted workshops, what did these look like?

Q7: What is the most significant aspect of working with the local Indigenous communities at Highland Valley Copper?

Appendix B: HVC Indigenous Engagement Workshop Invitation

Figure B.1. Teck Workshop invitation sent to the Nlaka'pamux community in 2019.

Appendix C: Commercial Seed Germination Rates for Field Experiment

Germination rate data for western yarrow (*Achillea millefolium*) and arctic lupine (*Lupinus arcticus*) was unavailable.

SEEDCHECK TECHNOLOGIES INC.

Report of Seed Analysis
CFIA Accredited Laboratory No. 1215

LAB#: 19-92884

101, 5906-50 Street
Leduc, Alberta T9E 0R6
Phone: (780) 980-8324
Fax: (780) 980-8375
www.seedcheck.net

Customer: Premier Pacific Seeds Ltd.
#203, 19315 - 96 Avenue
Surrey, B.C. V4N 4C4

Sender Information:

SeedType:	Bluebunch wheatgrass
Scientific Name:	(Pseudoroegneria spicata)
Lot#:	8DH501-24

Analyzed According to Canadian Methods & Procedures for Testing Seed

Tests: Germination , Canadian Purity,

Total Grams Analyzed: 50.30	Per 25	Date Received: Mar 11, 2019 Purity Date: Mar 11, 2019	Per 25
Prohibited Noxious:	0	**Other Crop Seeds:**	
Primary Noxious:			
Total Primary	**0**		
Secondary Noxious:		**Total Other Crop Seeds**	**0%**
(Bromus tectorum) Downy brome	3	Sweet Clover (Melilotus sp.)	0
		Brassica spp.	0
		Ergot Bodies	0%
Total Primary & Secondary Noxious	**3**		
Other Weed Seeds:		**Percentage Test:**	2.064g
		Pure seed %	98.9
		Other crop %	0.0
		Weed Seed %	0.0
		Inert matter%	1.1
		Date of Germination	3/25/19
		% GERMINATION	79
		Abnormal Seedlings%	4
		Dead Seed%	17
		Fresh Seed%	0
Total Noxious & Other Weed Seeds	**3**	Pure Living Seed%	78

Advisory Tests & Remarks:

SENIOR MEMBER
OF
COMMERCIAL SEED ANALYSTS ASSOCIATION CANADA INC.
124
Lisa Greenan

MONTANA
STATE UNIVERSITY

Montana State Seed Lab

PO Box 173145
Bozeman, MT 59717-3145
Laboratory Report Of Analysis

Account No.	Date Received	Date Completed	Lab Number
2132	**01/30/17**	**02/07/17**	**17-3178**

Seaborn Seeds, Inc.
Box 8, Site 11, R.R. 3
Rocky Mountain House, AB T4T 2A3

Information Provided by Sender

Product	VNS
Kind	Fescue, Idaho
Genus/Species	Festuca idahoensis
Lot Number	16-1438-216
Class	Service

Purity Analysis

Component in 2.9549 grams		**Purity**
Fescue, Idaho *Festuca idahoensis*		95.34%
	Weed seed	0.00%
	Crop seed	0.01%
	Inert matter	4.65%

Viability Analysis

Germ Date	**Germ**	**Dormant**	**Hard**	**Viable**
-N-	-N-	-N-	-N-	-N-

Other Crop Seeds in 2.9549 grams	**# Seeds**	**# per lb**
Canarygrass, reed *Phalaris arundinacea*	1	154

Noxious Weed Seeds in 30 grams None Found

For: MT

(P)Prohibited Noxious (R)Restricted Noxious

Weed Seeds None Found

Other Determinations

TZ test *Fescue, Idaho* 92 %

Status: Completed

Tests Requested: Purity, TZ test. No other tests requested.

This is not a bill. Please do not pay until we send you an invoice.

Signature: Bridget A. Westfall
Bridget Westfall, RST
Seal #139

SEEDCHECK TECHNOLOGIES INC.

Report of Seed Analysis
CFIA Accredited Laboratory No. 1215

LAB#: 18-88519

101, 5906-50 Street
Leduc, Alberta T9E 0R6
Phone: (780) 980-8324
Fax: (780) 980-8375
www.seedcheck.net

Customer: Premier Pacific Seeds Ltd.
#203, 19315 - 96 Avenue
Surrey, B.C. V4N 4C4

Sender Information:	
SeedType:	Idaho fescue
Scientific Name:	(Festuca idahoensis)
Lot#:	16-1438-216

Tests: Germination , (Non-Tabled), Tetrazolium,

Test Results According to Canadian Methods & Procedures

Date Received	Oct 18, 2018
Date of Germination	Nov 08, 2018
% GERMINATION	91
Abnormal Seedlings%	2
Dead Seed%	7
Fresh Seed%	0
Method:	TP 15/25C, 21 days

Advisory Test / Remarks

Tetrazolium % Viable: 87 Oct 19, 2018

SENIOR MEMBER OF

COMMERCIAL SEED ANALYSTS ASSOCIATION CANADA INC.

BioVision SEED LABS

Work Order 4004758-01

Received 7/04/2017 Completed 7/18/2017

Tested By: BioVision Seed Labs
12803 100 Street
Grande Prairie , Alberta T8V 4H3
P (780) 532-8890
CFIA Acc #1213

SENIOR MEMBER OF

LEE-ANNE ALDE

Sample of: Rocky Mountain Fescue
Sample ID: 4116

Report of Analysis

Purity - Fescue		Completed: 7/5/2017		Results Per: 25 grams	Grams Analyzed: 22	Method	CDN
Noxious Weed Seeds		**Other Weed Seeds**		**Other Crops**		**Total Primary + Secondary**	0
Prohibited Noxious Total	0	Other Weed Seeds Total	5.7	Other Crops Total	< 2 %	Total Weeds	5.7
Primary Noxious Total	0	Dandelion	3.4	Slender Wheatgrass			
Secondary Noxious Total	0	Hawksbeard (spp.)	2.3	Fowl Bluegrass		Analyst Remarks	
				Brassica/Sweet Clover/Ergot/Sclerotia		APPROXIMATE NUMBER OF SEEDS PER GRAM 1145	
				Brassica spp.	0		
				Ergot	0%		
				Sweet Clover	0		

Germination - Fescue — Completed: 7/18/2017 — Grams Analyzed: 2.2014

PURE SEED COMPONENTS % — Method: CDN | VIABILITY ANALYSIS % — Method: CDN

Seed Name	Pure Seed	Other Crop	Weed Seed	Inert	PLS	Germ	Hard	Germ & Hard	Fresh	Abnormal	Dead	Analyst Remarks
Rocky Mountain Fescue	98.7	0.0	0.0	1.3	-	99	0	-	0	0	1	

SEEDCHECK TECHNOLOGIES INC.

Report of Seed Analysis
CFIA Accredited Laboratory No. 1215

LAB#: 18-86999

101, 5906-50 Street
Leduc, Alberta T9E 0R6
Phone: (780) 980-8324
Fax: (780) 980-8375
www.seedcheck.net

Customer: Premier Pacific Seeds Ltd.
#203, 19315 - 96 Avenue
Surrey, B.C. V4N 4C4

Sender Information:	
SeedType:	Sandberg bluegrass
Scientific Name:	(Poa secunda)
Lot#:	010-215-123A

Analyzed According to Canadian Methods & Procedures for Testing Seed

Tests: Germination , (Non-Tabled), Canadian Purity,

Total Grams Analyzed: 12.04	Per 25g	Date Received: May 22, 2018 Purity Date: May 23, 2018	Per 25g
Prohibited Noxious:	0	**Other Crop Seeds:**	
Primary Noxious:			
Total Primary	**0**		
Secondary Noxious:		**Total Other Crop Seeds**	**0%**
		Sweet Clover (Melilotus sp.)	0
		Brassica spp.	0
		Ergot Bodies	0%
Total Primary & Secondary Noxious	**0**		
Other Weed Seeds:		**Percentage Test:**	1.214g
		Pure seed %	97.9
		Other crop %	0.0
		Weed Seed %	0.0
		Inert matter%	2.1
		Ergot (included in inert)%	0.0
		Date of Germination	6/14/18
		% GERMINATION	74
		Abnormal Seedlings%	12
		Dead Seed%	14
		Fresh Seed%	0
Total Noxious & Other Weed Seeds	**0**		

Advisory Tests & Remarks:

Germination Method: TP15/25C 20 days, with prechill and potassium nitrate

This Crop Kind does not fall on the Canadian Grade Tables. AOSA Rules used for weights.

SENIOR MEMBER
OF

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Lisa Greenan

SEEDCHECK TECHNOLOGIES INC.

Report of Seed Analysis
CFIA Accredited Laboratory No. 1215

101, 5906-50 Street
Leduc, Alberta T9E 0R6
Phone: (780) 980-8324
Fax: (780) 980-8375
www.seedcheck.net

LAB#: 19-91724

Customer: Premier Pacific Seeds Ltd.
#203, 19315 - 96 Avenue
Surrey, B.C. V4N 4C4

Sender Information:

SeedType:	Sandberg bluegrass
Scientific Name:	(Poa secunda)
Lot#:	010-215-123A

Tests: Germination , (Non-Tabled),

Test Results According to Canadian Methods & Procedures

Date Received	Jan 24, 2019
Date of Germination	Feb 21, 2019
% GERMINATION	73
Abnormal Seedlings%	5
Dead Seed%	22
Fresh Seed%	0
Method:	TP 15/25C, potassium nitrate, 28 days

Advisory Test / Remarks

SENIOR MEMBER
OF

SEED ANALYSTS COMMERCIAL CANADA INC. ASSOCIATION

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Lisa Greenan

SEEDCHECK TECHNOLOGIES INC.

Report of Seed Analysis
CFIA Accredited Laboratory No. 1215

LAB#: 19-91047

101, 5908-50 Street
Leduc, Alberta T9E 0R6
Phone: (780) 980-8324
Fax: (780) 980-8375
www.seedcheck.net

Customer:

Sender Information:

SeedType:	Junegrass
Scientific Name:	(Koeleria macrantha)
Lot#:	18-1438-226

Analyzed According to Canadian Methods & Procedures for Testing Seed

Tests: (Non-Tabled), Canadian Purity, Tetrazolium,

Total Grams Analyzed: 10.05	Per 25	Date Received: Jan 09, 2019 Purity Date: Jan 09, 2019	Per 25
Prohibited Noxious:	0	**Other Crop Seeds:**	
		(Poa pratensis) Kentucky bluegrass	
		(Poa palustris) Fowl bluegrass	
		(hard/fine leaved/sheeps) Festuca spp.(small)	
Primary Noxious:			
Total Primary	**0**		
Secondary Noxious:		**Total Other Crop Seeds**	**<2%**
		Sweet Clover (Melilotus sp.)	0
		Brassica spp.	0
		Ergot Bodies	0%
Total Primary & Secondary Noxious	**0**		
Other Weed Seeds:		**Percentage Test:**	1.006g
		Pure seed %	98.4
		Other crop %	0.9
		Weed Seed %	0.0
		Inert matter%	0.7
		Ergot (included in inert)%	0.0
Total Noxious & Other Weed Seeds	**0**		

Advisory Tests & Remarks:

This Crop Kind does not fall on the Canadian Grade Tables. AOSA Rules used for weights.

Tetrazolium % Viable: 93 Jan 10, 2019

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SEEDCHECK TECHNOLOGIES INC.

Report of Seed Analysis
CFIA Accredited Laboratory No. 1215

101, 5906-50 Street
Leduc, Alberta T9E 0R6
Phone: (780) 980-8324
Fax: (780) 980-8375
www.seedcheck.net

LAB#: 19-91757

Customer: Premier Pacific Seeds Ltd.
#203, 19315 - 96 Avenue
Surrey, B.C. V4N 4C4

Sender Information:

SeedType:	Rocky Mountain fescue
Scientific Name:	(Festuca saximontana)
Lot#:	4116

Tests: Germination , (Non-Tabled),

Test Results According to Canadian Methods & Procedures

Date Received	Jan 24, 2019
Date of Germination	Feb 14, 2019
% GERMINATION	94
Abnormal Seedlings%	1
Dead Seed%	5
Fresh Seed%	0
Method:	TP 15/25C, 21 days

Advisory Test / Remarks

SENIOR MEMBER
OF

SEED COMMERCIAL ANALYSTS ASSOCIATION CANADA INC

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Lisa Greenan

Appendix D: Mesocosm Greenhouse Germination Trial

INTRODUCTION

Understanding seedling germination during reclamation and restoration projects can be a major determinant of how the plant community is composed. Seed dormancy, purity, and viability of seed can limit successful establishment of the proposed target community. Seed dormancy is a block to the completion of germination under favorable conditions and can be separated by physiological inhibitors in the seed coat. Gibberellic acids and physical scarification has been shown to significantly increase maximum germination rates (Nasri et al. 2014, Watkinson et al. 2020). It is also important to understand each plants life history and consider the ecology of each desired plant species, combined with environmental conditions of the habitat to maximize successful seedling germination (Baskin and Baskin 1998).

Prior to conducting a mesocosm greenhouse study in the winter of 2020, a seed germination trial was conducted at the Thompson Rivers University Research Greenhouse (Kamloops, B.C.) to examine seed viability, and determine PLS rates for mesocosm seed application. The objectives of the trial were to: 1) determine the viability of native seed stock acquired for the greenhouse study, 2) determine PLS rate applied to each mesocosm unit.

MATERIALS & METHODS

Seed Source

Seeds were purchased from ‘Quality Seed Collections Ltd.’ located in Kamloops, B.C., Canada. All seeds are pickseed directly from B.C.

Experimental Design

Germination rates of six study species (Table D-1 & D-2.) were assessed for two treatments: ‘GA_3’ and ‘water’. Each treatment was replicated three times (6 species x 2 treatments x 3 replicates per treatment). The germination trial was conducted over a 30-day period under controlled conditions operated and maintained by Argus™ control systems (natural and artificial light: day/night 18h/6h; temperature: day/night 21°C; humidity: 50-60%). A total of thirty-six glass petri dishes (35mm diameter x 18mm deep) were lined with filter paper and labelled by species and treatment. Each dish received 30 seeds of a single species and then randomly assigned to a single block. Petri dishes were placed in the center of the greenhouse pod (most stable temperature and light). Petri dishes were monitored daily for signs of germination and mold. Filter paper was kept saturated with either a) 1000 ppm (10-mg L^{-1}) Gibberellic acid solution (GA_3) (Adbulhafiz et al. 2020) or b) deionized water. Seeds were considered germinated when the radicle length reached twice the radicle width. Germinated and moldy seeds were removed from the petri dishes upon observation.

Statistical Analysis

Mean cumulative germination rates were calculated for each 2-day interval in order to show germination success over the 30-day trial period. Descriptive statistics were used to compare germination rates across species.

RESULTS & DISCUSSION

Viability of Native Seed

Germination rates of native grasses ranged from 60 to 78%, with *Festuca campestris* having the lowest germination rate. Application of GA_3 appears to have no significant effect on the germination of the native grasses as the cumulative rate was lower in both cases. With respect to native forb germination, their appears to be no response to GA_3 treatment with germination rate reaching 48% (Figure D.1). Legume species germination rate was the lowest across all functional groups ranging from 11 % in *Oxytropis campestris* to 35% in *Lupinus arcticus*. GA_3 treatment appeared to have no significant effect with germination.

Castilleja miniata, unfortunately failed to germinate after many attempts and varying treatments including cold and wet stratification and flash freezing (Figure D.1). As outlined by Luna (2005), it is recommended to cold and wet stratify for 30 – 150 days, while I only allowed 30-days. As this species is a hemi-parasite it is also recommended to host well with small bunchgrasses such as the two selected native species in this study. In the future I would allow longer cold and wet stratification while examining different host plants to examine success rates of germination.

Pure Live Seed

Pure live seed is a measure of seed viability and quality and is an important factor in rehabilitation and restoration contexts to project the final composition of a vegetative community. Pure live seed was calculated by multiplying percent germination by percent pure seed, as per Dobb and Burton (2012). Grasses represent the largest contribution to PLS/m^2 with a total of 1100 seeds/m^2 due to the highest cumulative germination rate, while forbs and legumes represent approximately the same proportion at 390 seeds/m^2 and 372 seeds/m^2, respectively (Table D-2). A cumulative PLS rate of 1873 seeds/m^2 was achieved which represents an acceptable application rate based current on reclamation and restoration standards presented by Barr et al. (2017) and Burton et al. (2006).

SUMMARY & CONCLUSIONS

- Germination rates of grass species reached the highest levels compared to other functional groups.
- *Castilleja miniata* requires significant seed preparation that mimics over wintering freeze thaw cycles to effectively germinate as per Luna (2005). Additionally, the seed acquired may have been not viable or immature resulting in lack of any germination after multiple treatments.
- Treatment with GA_3 appears to have no significant effect on germination rates and seed emergence in all cases.
- Grass species represent the largest portion of PLS due to the highest achieved germination rates.

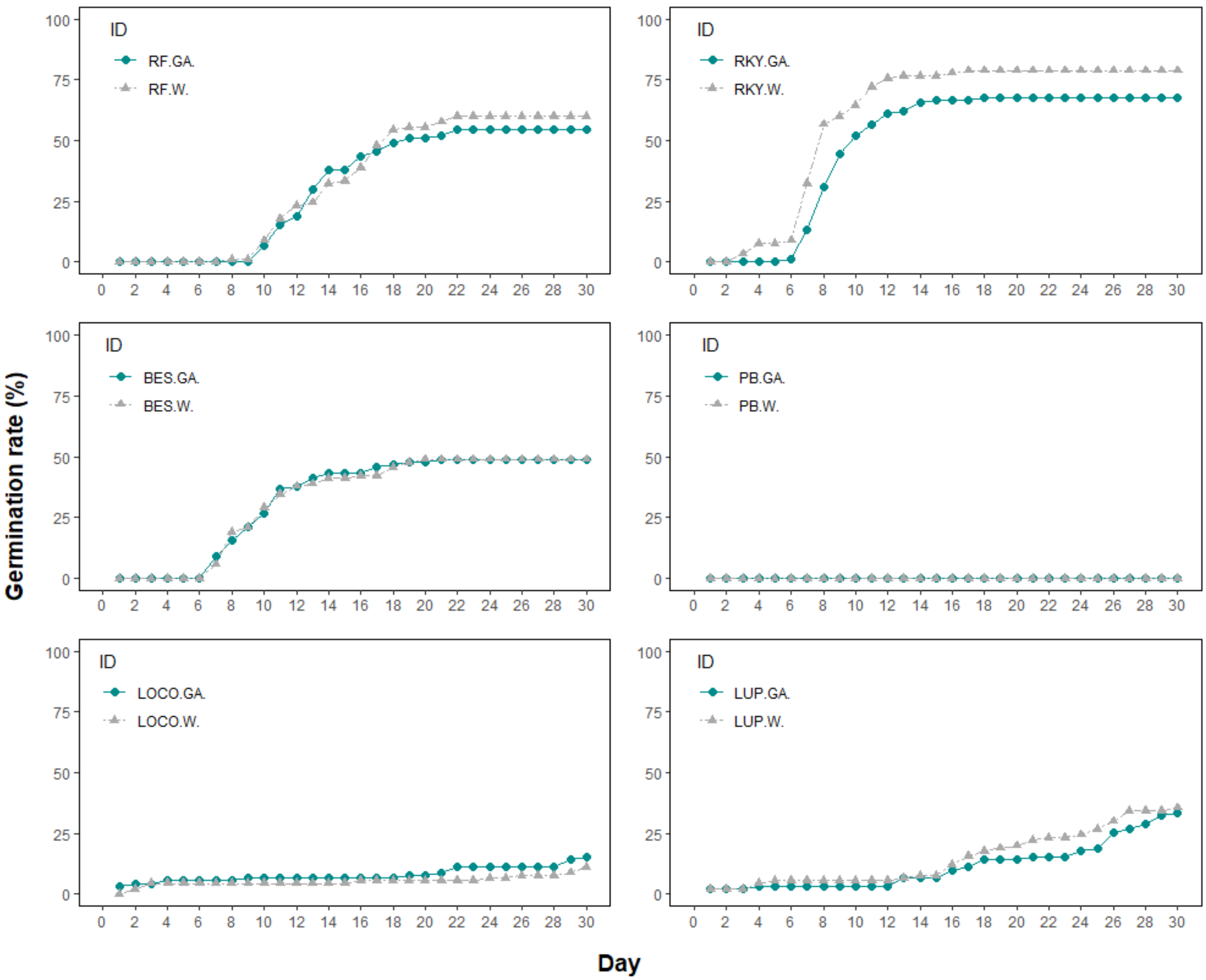

Figure D.1. Cumulative germination rates of selected species for the greenhouse mesocosm experiment over a 30-day greenhouse trial. Treatments included deionized water (water) and Gibberellic acid (GA_3) 1000ppm solution. RF - Rough Fescue (*Festuca campestris*), RKY - Rocky Mountain Fescue (*Festuca saximontana*), BES – Brown Eyed Susan (*Gaillardia aristata*), PB – Common Red Paintbrush (*Castilleja miniata*), LOCO – Field Locoweed (*Oxytropis campestris*), LUP – Arctic Lupine (*Lupinus arcticus*).

Table D-1. Mean cumulative germination rates (%) for each of the study species during a 30-day greenhouse germination trial. Treatments were either deionized water (Water) or 1000 ppm Gibberellic acid solution (GA_3).

Germination Rate (Cumulative sum)

Grasses												
	Water						**Gibberellic Acid**					
Day	*Festuca campestris*			*Festuca saimontana*			*Festuca campestris*			*Festuca saimontana*		
	x̄	sd	SE	x̄	sd	SE	x̄	sd	SE	x̄	sd	SE
1	0	0	0	0	0	0	0	0	0	0	0	0
10	8.88	8.38	4.84	64.44	7.69	4.44	6.66	6.66	3.84	52.22	15.75	9.09
20	55.55	11.7	6.75	78.88	13.47	7.77	51.11	3.84	2.22	67.77	12.61	7.28
30	60	6.66	3.84	78.88	13.47	7.77	54.44	1.92	1.11	67.77	12.61	7.28
Forbs												
	Gaillardia aristata			*Castilleja miniata*			*Gaillardia aristata*			*Castilleja miniata*		
	x̄	sd	SE	x̄	sd	SE	x̄	sd	SE	x̄	sd	SE
1	0	0	0	0	0	0	0	0	0	0	0	0
10	28.88	6.93	4	0	0	0	26.66	15.27	8.81	0	0	0
20	48.88	11.7	6.75	0	0	0	47.77	10.18	5.87	0	0	0
30	48.88	11.7	6.75	0	0	0	48.88	8.38	4.84	0	0	0
Legumes												
	Oxytropis campestris			*Lupinus arcticus*			*Oxytropis campestris*			*Lupinus arcticus*		
	x̄	sd	SE	x̄	sd	SE	x̄	sd	SE	x̄	sd	SE
1	0	0	0	0	0	0	0	0	0	0	0	0
10	4.44	5.09	2.93	5.55	3.84	2.22	6.66	3.33	1.92	3.33	3.33	1.92
20	5.55	5.09	2.93	20	17.32	10	7.77	5.09	2.93	14.4	7.69	4.44
30	11.11	1.92	1.11	35.55	15.39	8.88	15.55	5.09	2.93	33.33	3.33	1.92

Table D-2. Pure live seed (PLS) calculations by species based on germination rate and seeding rate.

Species	Germination Rate (%)	PLS/200 seed	PLS/0.25m2	PLS/m2
Festuca campestris	60	120	120	480
Festuca saximontana	78.8	157	157	630
Gaillardia aristata	48.8	97	97	390
Castilleja miniata	0	0	0	0
Oxytropis campestris	11.1	22	22	88
Lupinus arcticus	35.5	71	71	284

Literature Cited:

Adbulhafiz F, Mohammed A, Kayat F, Zakaria S, Hamzah Z, Pamuru R, Gundala P, Reduan M. 2020. Micropropagation of Alocasia longiloba Miq and Comparative Antioxidant Properties of Ethanolic Extracts of the Field-Grown Plant, In Vitro Propogated and In Vitro-Derived Callus.

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Appendix E: Plant Inventory for Mesocosm Greenhouse Experiment

Table E-1. Plant inventory and functional group classification for observed species within mesocosm experimental study.

Scientific Name	Common Name	Functional Group Classification
Achillea millefolium	Yarrow	Forb
Bromus ciliatus	Fringed Brome	Non-desirable Grass
Bromus inermis	Smooth Brome	Non-desirable Grass
Dactylis glomerata	Orchardgrass	Non-desirable Grass
Descurainia sophia	Flixweed	Ruderal Herb
Elymus trachycaulus	Slender Wheatgrass	Non-desirable Grass
Festuca spp. (Festuca saximontana & Festuca campestris)	Rocky Mountain Fescue & Rough Fescue	Native Grass
Gaillardia aristata	Brown eyed susan	Forb
Linaria vulgaris	Common toadflax	Ruderal Herb
Lupinus arcticus	Arctic lupine	Legume
Medicago sativa	Alfalfa	Legume
Oxytropis campestris	Field locoweed	Legume
Poa spp.	N/A	Non-desirable Grass
Rumex crispus	Curled dock	Ruderal Herb
Sisymbrium loeselii	Loesels tumble mustard	Ruderal Herb
Taraxacum officinale	Common dandelion	Ruderal Herb

Appendix F: Plant Inventory for Field Sampling at Highland Valley Copper

Table F-1. Plant inventory and functional group classification for observed species within the field study in alphabetical order by scientific name.

Scientific Name	Common Name	Functional Group Classification
Achillea millefolium	Yarrow	Forb
Bromus inermis	Smooth Brome	Non-desirable Grass
Cinna latifolia	Drooping woodreed	Non-desirable Grass
Descurainia sophia	Flixweed	Ruderal Herb
Elymus trachycaulus	Slender Wheatgrass	Non-desirable Grass
Festuca spp. (Festuca saximontana & Festuca idahoensis)	Rocky Mountain Fescue & Idaho Fescue	Native Grass
Hieracium albiflorum	White Hawkweed	Forb
Medicago sativa	Alfalfa	Legume
Poa spp.	N/A	Non-desirable Grass
Poa secunda	Sandberg Bluegrass	Native Grass
Pinus contorta	Lodgepole pine	Tree
Rumex crispus	Curled dock	Ruderal Herb
Sisymbrium loeselii	Loesels tumble mustard	Ruderal Herb
Taraxacum officinale	Common dandelion	Ruderal Herb
Thinopyrum intermedium	Intermediate wheatgrass	Non-desirable Grass
Trifolium repens	White clover	Legume

Appendix G: Extraneous Analysis for Field Experiment at Highland Valley Copper Mine

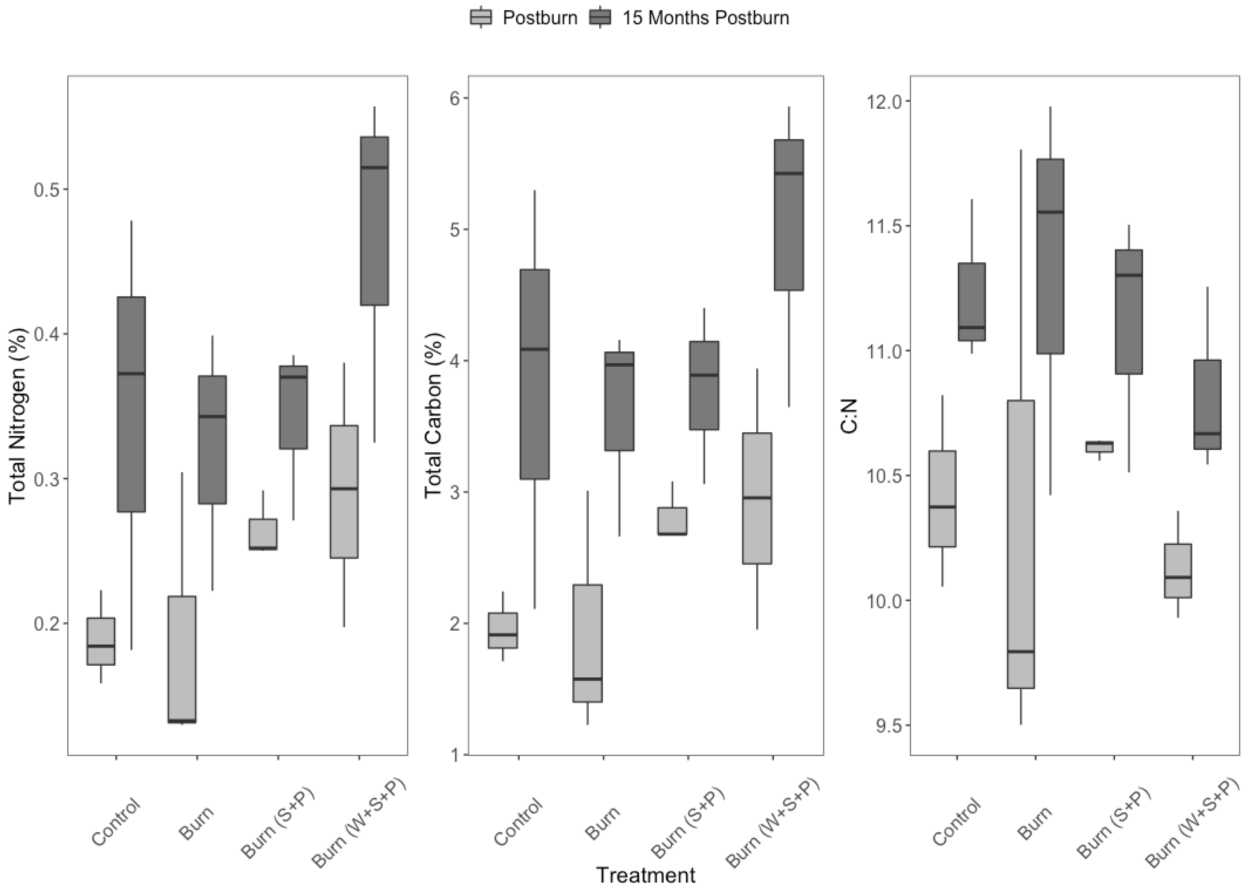

Figure G.1. Total nitrogen, carbon, and carbon to nitrogen (C:N) ratio from the top 15cm of soil extracted from treatment plots comparing postburn to fifteen months postburn. (n = 3 within all groups)

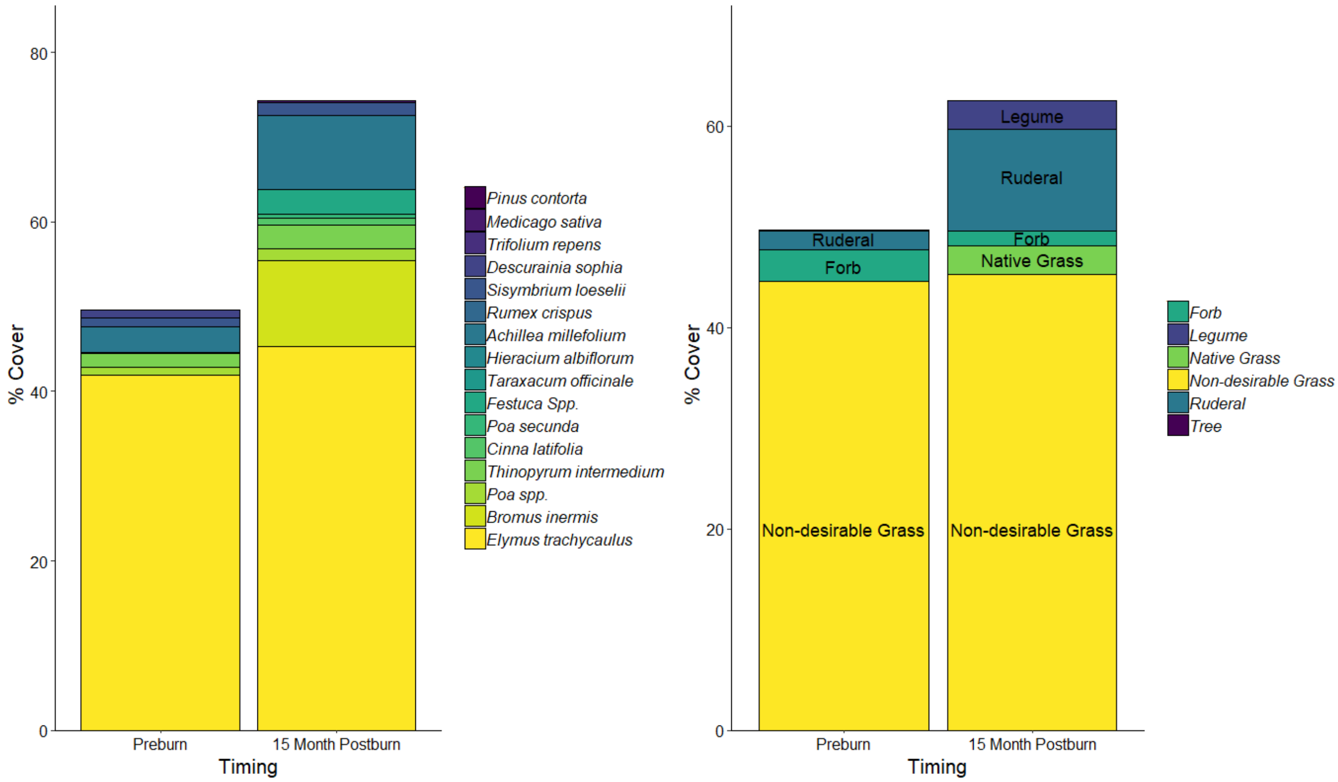

Figure G.2. Mean percent plant cover by species and functional group across all experimental plots by timing of preburn to fifteen months postburn.

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Appendix H: Extraneous Analysis for Mesocosm Greenhouse Experiment

Effect of Disturbance and Timing on Species Richness

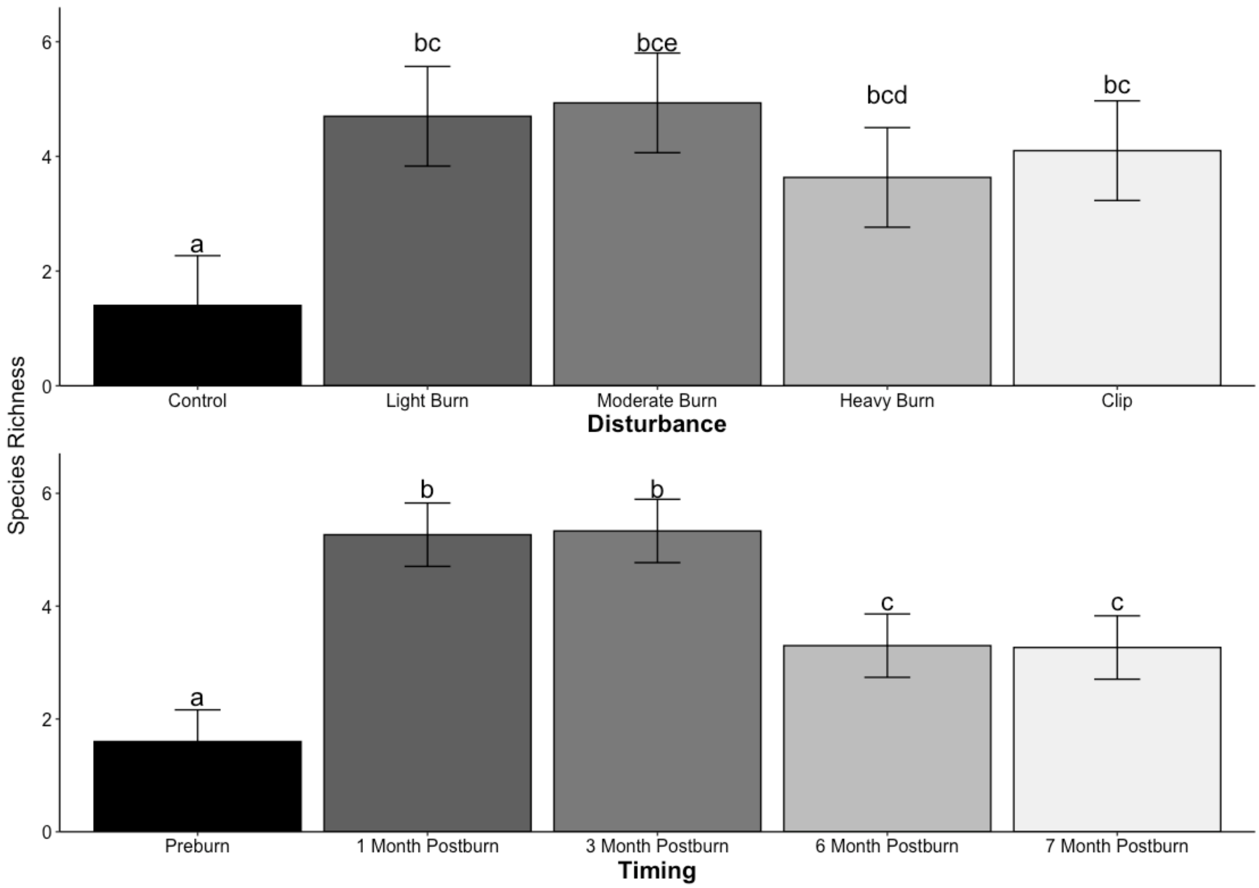

Figure H.1. Mean species richness examining the effects of Timing (n = 30, +/- 95% C.I.) and Disturbance (n = 30, +/- 95% C.I.) .) Bars with different letters indicate significant differences. Pairwise comparisons between the treatment levels were adjusted with BH corrections.

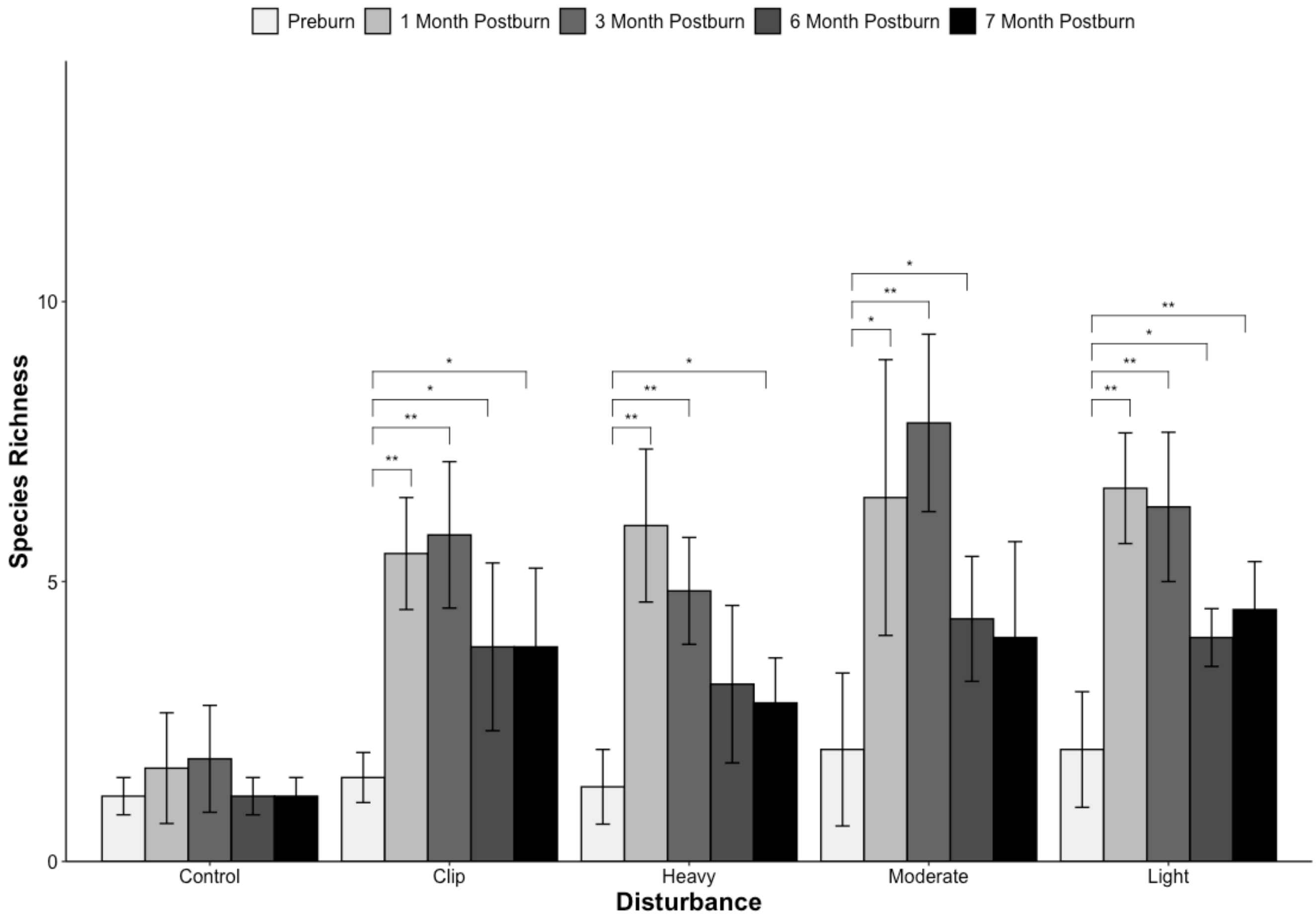

Figure H.2. Interaction effect between disturbance treatment and timing, plotted as mean species richness (n = 6, +/- 95% C.I.). Pairwise comparisons between the base mean of ‘pre-disturbance’ in each treatment were completed and adjusted with BH corrections. ‘*’ $p < 0.05$, ‘**’ $p < 0.01$. Non-significant values were not plotted.