**The** **Effectiveness of Seeding for Mitigating Erosion Post-High Severity Wildfire**

By

**Jollee Perrier**

AN ESSAY SUBMITTED FOR NRSC 4230 IN PARTIAL

FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF

BACHELOR OF NATURAL RESOURCE SCIENCE

In the Department

of

NATURAL RESOURCE SCIENCES

FACULTY OF SCIENCE

at

THOMPSON RIVERS UNIVERSITY

BY JOLLEE PERRIER

Logo

Description automatically generated

WINTER 2021

# **ABSTRACT**

The intention for seeding following high-severity wildfires is to enhance ground cover and reduce bare ground to reduce water runoff, soil erosion, and non-native plant invasion. Seed mixes generally contain non-native species for their quick growth and extensive root systems. Although there is a lack of long-term studies on effects from seeding post-fire, there are many current informative studies. The objectives of my literature review are 1) examine current literature to see if seeding post wildfire is effective in mitigating erosion, and 2) assess the plants ecology that are in the 2021/2022 BC post-wildfire seed mixes used for erosion control. I reviewed a total of 25 papers and narrowed down to nine using definitions to quantify quality of evidence and erosion effectiveness. Eight out of the nine studies I reviewed indicated that seeding was ineffective. The main reason seeding was concluded to be ineffective is that of unpredictable weather events such as rain, wind, and droughts causing seeds to be washed away or preventing germination success during the fall and spring. One recommendation is to use mulch post fire as its effectiveness can reach 90% efficacy in reducing sediment loss. As well, if having to seed must consider ecosystem long-term health thus, selecting species that are short-lived and low persisting and monitor future results.

TABLE OF CONTENTS

[ABSTRACT i](#_Toc97886460)

[LIST OF TABLES iii](#_Toc97886461)

[INTRODUCTION 1](#_Toc97886462)

[WILDLAND FIRE AND CLIMATE CHANGE 1](#_Toc97886463)

[REHABILITATION 3](#_Toc97886464)

[OBJECTIVES 4](#_Toc97886465)

[METHODS 4](#_Toc97886466)

[RESULTS 8](#_Toc97886467)

[SEEDING FOR EROSION CONTROL EFFECTIVENESS 8](#_Toc97886468)

[B.C SEEDING MIX 8](#_Toc97886469)

[DISCUSSION 8](#_Toc97886470)

[METHODS OF ASSESSING EROSION CONTROL 8](#_Toc97886471)

[SEEDING EFFECTIVENESS FOR EROSION CONTROL 9](#_Toc97886472)

[BC SEED MIX 10](#_Toc97886473)

[MANAGEMENT RECCOMENDATIONS 12](#_Toc97886474)

[LITERATURE CITED 14](#_Toc97886475)

[APPENDICES 17](#_Toc97886476)

[APPENDIX 1. PLANT SPECIES COMMON AND SCIENTIFIC NAMES 17](#_Toc97886477)

[APPENDIX 2. REFERENCES INCLUDED IN THE REVIEW (WITH QUALITY OF EVIDENCE RATINGS) 18](#_Toc97886478)

# **LIST OF TABLES**

[TABLE 1. Definitions of seeding effectiveness from seeding post-fire 6](#_Toc97886594)

[TABLE 2. Definitions of quality of evidence of literature 6](#_Toc97886595)

[TABLE 3. The 6 recommended seed mixes for soil stabilization/invasive plant prevention/erosion control post-fire for BC 7](#_Toc97886596)

[TABLE 4. Compilation of literature and reviewing their methods, results ad discussion and comparing treatment type, fire severity, erosion measure used, effectiveness, seeding rate, seed mix, plant cover percent, and ecosystem type 5](#_Toc97886597)

[TABLE 5. The plant species contained in the seed mixes proposed in BC seeding guidelines with their functional group and nativity, persistence, longevity, and erosion control efficacy 7](#_Toc97886598)

[TABLE A 1. List of common and scientific names of all plant species listed in this paper 17](#_Toc97886599)

# **INTRODUCTION**

## **WILDLAND FIRE AND CLIMATE CHANGE**

Fire is an important natural disturbance in Western North America that influences biodiversity and nutrient cycling (McLauchlan et al. 2020). Fire on the landscape has been a tool that First Nations have used over millennia. First Nations people would manage fire to increase forage production and medicinal plants, create fuel breaks around camps, and many other objectives (MacDonald and Hudson 2012; ICT 2019). When Europeans settled in North America, the First Nations were forced from their traditional lands to reserves, and populations were decimated by disease in the 1800s, fire management changed from First Nation traditional knowledge to a foreign European approach (Lyon et al. 2000; ICT 2019). In the 1900s, settlers viewed fire as destroying timber yield therefore firefighting and fire suppression efforts were put into policy (Lyon et al. 2000; ICT 2019). Although we have successfully suppressed wildfire over the past 80 years in North America, in British Columbia the top 3 record years for area burned in one fire season have occurred in the last 5 years (Tzembelicos et al 2018); in 2018, 1.35 million hectares (ha) burned, in 2017 1.2 million ha, and in 2021, 868,203 ha burned (BC Government 2021).

Fire severity is a qualitative term, referring to environmental and soil impacts specifically, how much above and below ground organic matter remains and the extent of charring of plant materials (Neary et al. 2005). Fire severity is defined into low, moderate, and high classes which are defined by the magnitude of impact on soil characteristics (Santín and Doerr 2016). High severity fires cause greater erosion and water run off impacts than low severity. The total area of high severity burned has increased 30% between 1970-1990 in USA, Forest Service Land (Robichaud et al. 2000). Soils are a valuable resource, but they are being eroded 13-40x faster than renewal rates due to anthropogenic factors, mainly agriculture which loses 75 billion tons each year, making this resource non-renewable (Zuazo and Pleguezuelo 2008; Santín and Doerr 2016). Erosion rates are typically less than 0.5 Mg/ha, but fire can cause these rates to exceed 20 Mg/ha (Elliot et al. 1996). During high severity fires a substantial amount of ground cover is removed causing many impacts to the environment. This disturbance causes concern of non-native invasive species ability to colonize the area and impact the future plant community. Non-native species can affect nutrient cycling, alter native plants and wildlife, livestock, and cause negative economic impacts (Pyke et al. 2013; CCIS 2022). Environmental impacts are the creation of hydrophobic soils, increased soil erosion and sedimentation, which in turn affect water quality, streamflow regime, peak flows, and flooding events (Neary et al. 2005). Sediment loss is significantly higher in burned areas than non-burned (Johansen et al. 2001; Badía and Martí 2008) and reaches peak loss in summer, fall, or spring during major rainfall or storm events the first year after the fire (Curren et al. 2006). People’s homes, infrastructure, and resources such as clean water are threatened by post-fire landslides and floods.

The climate strongly drives local weather, fuel moisture content and in conjunction with forest structure and composition, these are factors that are important in predicting fire behavior prior to forest fire ignition (﻿Halofsky et al. 2020; Flannigan et al. 2000). Nearly the entire globe is expected to increase in temperature which in turn will affect wildfire activity (Flannigan et al. 2013). Higher temperature predictions will increase evapotranspiration and lightning activity, decrease fuel moisture, and cause longer fire seasons (Sarris 2014; Flannigan et al. 2013). Climate change predicts prolonged droughts and when paired with historical fire suppression that resulted in fuel build up, fire regimes may alter and increase the frequency of high severity fires (Halofsky et al. 2020). There is also evidence that the frequency of high severity fires is not higher than historical averages. Baker (2015), concluded that the frequency of high severity fires will increase several decades from now. His study shows that current high severity fires are within or below historical averages, other than in regions in Southwest and Rocky Mountains where there is an upward trend of high severity. Flannigan et al., (2000) also mentioned that areas burned currently are lower than historical averages over the past 500 years in the United States, but the likeliness of increasing severity with climate change is still of concern (Haider et al. 2019).

The wildland-human interface (WUI) is where housing meets wildland vegetation and is where wildfire impacts are most pronounced (Radeloff et al. 2018). With increasing WUI, the impacts of fire on humans increases as well including human caused fires, and post-fire events such as flooding and erosion. There are many ways to mitigate these impacts including firefighting, rehabilitation, hazardous fuels reduction, community assistance, accountability, and policy implementation.

## **REHABILITATION**

Canada invests between $800 million to $1.4 billion annually on wildland fire protection including mitigation and fire response costs. Rehabilitation is implemented in the Wildfire Act and Regulation, Forest and Range Practices Act, and Forest Fire Prevention and Suppression Regulation (FFPSR) (FBP 2004). FFPSR deals with site rehabilitation and states that is required to ensure natural drainage and surface soil erosion is mitigated to provide environmental and public safety. There are many rehabilitation techniques that can be applied to a site such as grass seeding, contour-felled logs, mulch, slope and stream bank stabilization, and re-establishing slopes and natural drainage patterns. Seeding is a common option used in BC following wildfires to prevent erosion, minimize invasive plants, and provide forage for livestock by obtaining ground cover. There are a variety of seed mixes used depending on the site specific objectives. The seeding rates recommended by BC seeding guidelines are 75 kg/ha hydraulically, 20 kg/ha broadcast by hand or ATV, and 20-40 kg/ha Heli-seeding (Range Branch 2021). Ground cover includes vegetation and litter and for good hydrologic condition cover is greater than 75%, approximately 60% to 70% to effectively control erosion, and a 30% threshold to start reducing erosion rates (Beyers 2004; Robichaud et al. 2000). The main effort is obtaining these ground cover percentages when erosion impacts are at their greatest threat because, within the first year post-fire there is little to no ground cover after a high severity fire (Robichaud et al. 2000; Rough 2007).

Under the Canada Seed Act, a seed certificate must be obtained which discloses the purity and germination success of the seed mix. Seed mixes used must be graded and labeled. There is no minimum standard for native seeds and grade designation which may be problematic because, a seed grade common No.2 can contain more noxious weeds than common No.1 (Range Branch 2017). This raises for concern of invasive species introduction through seed mixes. Invasive species threaten biodiversity, alter fire regimes, displace native vegetation, affect nutrient cycling, and are often very difficult to eradicate causing economic expenses (CCIS 2022). Range Branch (2021), states therefore, when making decisions to seed you must consider site sensitivity, invasiveness of species, species persistence, and if native species are readily available. BC’s post-wildfire seeding guidelines have proposed recommended seed mixes for the 2021/2022 season (Range Branch 2021), yet the mixes contain species that raise concern (Hulet et al. 2010; Jeschke et al. 2014; GeFellers et al. 2020). Although seeding is used as a common practice, many reviews have revealed that seeding may not be effective in erosion control (Beyers 2004; Zuazo and Plequezuelo 2008; Girona-García et al. 2021).

## **OBJECTIVES**

With changing climate predictions and fire effects directly impacting human’s health and safety, management for rehabilitation and mitigation efforts for wildfire is very prevalent. In BC, fire rehabilitation includes seeding as an option and the BC post-fire seeding guidelines for 2021/2022 recommends seed mixes for the objective of “stabilization/invasive plant prevention/erosion control” (Range Branch 2021). However, there are concerns with seeding effectiveness as well as the possibility of undesired species being added through the seed mix. Although there is a lack of long-term studies on effects from seeding post-fire, there are many current informative studies. These current studies are short-term, lasting around 2-4 years, but during this time is when erosion impacts are at their highest threat, therefore these studies are valid in assessing effectiveness for erosion control. Controversy if seeding is effective arises from older studies stating it is effective and continued use through managers over the years. Current literature suggests that seeding isn’t effective and that there are other methods we must consider.

Therefore, more research and implementation of science-based evidence must be compiled to understand effective rehabilitation strategies for erosion in areas that are prone to harming the environment and human safety. The objective of my study is to determine the following, 1) to examine current literature to see if seeding post wildfire is effective in mitigating erosion, and 2) assess the plant species ecology that are in the 2021/2022 BC post-wildfire seed mixes used for soil stabilization/invasive plant prevention/erosion control.

# **METHODS**

In January 2021, I collected data using a literature review approach, to evaluate the effectiveness of post-fire seeding for erosion control and examine plant species in BC’s proposed seed mixes for fire rehabilitation. Literature was collected using the search engines: JSTOR, Thompson Rivers University library database, and online government collections. The key terms used included: seeding AND fire, seeding AND wildlife, seeding AND effectiveness, seeding AND erosion, climate change AND wildfire, wildfire AND rehabilitation. A total of 25 peer-reviewed articles, case studies, meta-analysis, and reviews were examined.

I then used two meta-analyses to extract papers based on their quality of evidence rating determined by Beyers et al., (2011) and Peppin et al., (2010). The quality of evidence chosen for this study ranged between high and highest, focused on seeding effectiveness for erosion control, excluded other rehabilitation treatments such as mulching, and only included between the years 2000 – 2022 for relevance. Filtering out lower quality papers allows me to access higher quality papers that have statistically and scientifically reliable evidence. Table 1 outlines the definitions for quality of evidence and Table 2 outlines the definitions of effectives and ineffectiveness related to seeding for erosion; these definitions were adapted from Beyers et al., (2011) and Peppin et al., (2010). Based on these criteria a total of 9 papers were chosen and eight categories were used to quantify each paper: treatment type, fire severity, erosion measure used, effectiveness, seed rate, seed mix, total plant cover percentage first year post-fire, and ecosystem type. The quality of evidence chosen for each paper is seen in Appendix 2.

The seed mixes from BC post-fires seeding guidelines for soil stabilization/invasive plant prevention/erosion control in BC (Range Branch 2021) were used to evaluate the plant species (Table 3). I used Dob and Burton (2013) to analyze each plant species ecological characteristics of longevity, persistence, and erosion control effectiveness. This allowed me to compare each species and how they behave in their environment and conclude if they should be seeded in a natural ecosystem after a fire. The first two years after a fire are most concerning for erosion thus, a species longevity and persistence is important to consider because during these years are only when they are needed, and long-term studies that seeding has on native plant community greatly lacks in literature.

TABLE 1. Definitions of seeding effectiveness from seeding post-fire

|  |  |
| --- | --- |
| Definitions: Criteria for rating seeding treatment effectiveness1 | Effectiveness rating1 |
| Sufficient evidence exists to conclude that seeding was statistically or perceivably effective in decreasing erosion or increasing cover | Effective |
| Sufficient evidence exists to conclude that seeding was statistically or perceivably different in effectiveness, where treatments were counter-productive in their effectiveness, or seeding treatments in treated and untreated controls were not statistically or stated by the author to be different in their effectiveness for increasing cover or reducing erosion | Ineffective |

1(Beyers et al. 2011; Peppin et al. 2010).

TABLE 2. Definitions of quality of evidence of literature

|  |  |
| --- | --- |
| Definitions: Based on study design and statistical robustness1 | Quality of evidence1 |
| Statistically robust evidence obtained from replicated randomized and controlled experiments with sampling occurring after seeding treatments in areas burned by wildfire, prescribed burn, or slash pile burning | Highest |
| Unreplicated, controlled, observational or monitoring report (multiple locations); Before After Control Impact study (BACI) with reliable quantitative data from sampling occurring after seeding treatments in areas burned by wildfire, prescribed burn, or slash pile burning; peer-reviewed reviews on post-wildfire seeding | High |

1(Beyers et al. 2011; Peppin et al. 2010).

TABLE 3. The 6 recommended seed mixes for soil stabilization/invasive plant prevention/erosion control post-fire for BC

|  |  |
| --- | --- |
| Mix type1 | Species in mix1 |
| BG and PP | Annual Ryegrass  Crested Wheatgrass  Chewings Fescue  Hard Fescue |
| IDF and wetter | Annual Ryegrass  Orchard Grass  Crested Wheatgrass  Timothy  Redtop |
| Dry zone | Annual Ryegrass  Slender Wheatgrass  Chewings Fescue  Hard Fescue  Red Clover |
| Moist zone | Annual Ryegrass  Slender Wheatgrass  Chewings Fescue  Hard Fescue  Red Clover |
| Wet mix | Annual Ryegrass  Chewings Fescue  Orchard Grass  Redtop |
| Forage mix | Annual Ryegrass  Orchard Grass  Timothy  Redtop |

1Range Branch 2021.

# **RESULTS**

## **SEEDING FOR EROSION CONTROL EFFECTIVENESS**

From the high to highest quality evidence papers that were evaluated there was a consistent trend of seeding being ineffective for erosion control (Table 4). Seeding rates and seed mixes showed no difference in effectiveness in erosion control as the results all concluded that seeding was ineffective, except Díaz-Raviña et al., (2012). The studies had 2 different ways of testing erosion, sediment fence and plant cover. The sediment fence or sediment collection method collected the erosion run off from the hillslope and plant cover determined how much ground cover is present onsite. Combing same treatment types, the results for plant cover percent by treatment are seeding treatment 4.8-53%, seeding and mulching 26-45%, seeding and fertilization 11-18%, seeding and scarification 6%, and for one study it was not applicable as they did not collect plant cover data. The seeding treatment in Stella (2009) had the highest plant cover (53%) and Groen and Woods (2008) had lowest plant cover (4.8%) with seeding and scarification treatment. Across the studies there was a wide array of seeding rates and seed mixes which shows a lack in consistency. Groen and Woods (2008) seeded all native plants, Petersen et al., (2007), Stella (2009), and Wagenbrenner et al., (2006) seeded a mix of native and non-native, while all the other studies seeded with species that are non-native to North America.

## **B.C SEEDING MIX**

The species included in the BC seed mix as seen in Table 5 contain agronomics (non-native), perennial bunchgrasses, biennial bunchgrasses, and legumes. This table shows the species that are contained in the seed mixes as seen in Table 3. After going through each seed mix and compiling a list of the species used, I found that Range Branch (2021) chose 7 agronomic grasses, 1 native perennial bunchgrass, and 1 legume listed in their seed mixes. All species but, annual ryegrass (*Lolium multiflorum*) and red clover (*Trifolium pratense*) which have low persistence, range from moderate to high persistence. Annual ryegrass, red clover, and slender wheatgrass (*Elymus trachycaulus*) have low longevity where all others are moderate to high longevity. Redtop (*Agrostis gigantea*) is the only known species with high erosion control, while all others are either unknown or moderate.

TABLE 4. Compilation of literature and reviewing their methods, results ad discussion and comparing treatment type, fire severity, erosion measure used, effectiveness, seeding rate, seed mix, plant cover percent, and ecosystem type

| Reference | Treatment type | Fire severity | Erosion measure used | Effective or non-effective | Seeding rate | Seed mix | Plant cover | Ecosystem type (site) |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Robichaud et al. 2006 | Seeding and fertilizing | High severity | Sediment fence | Ineffective | ﻿34 kg/ha or 90 seeds/m2 | White winter wheat | 17-18% | Subalpine fir (North central Washington) |
| Wagenbrenner et al. 2006 | Seeding and mulching | High | Sediment fence | Ineffective | 34 kg/ha | Slender wheatgrass Mountain brome Commercial mix of sterile grass seed (Regreen®) | 26-45% | Ponderosa pine in Colorado |
| Peterson et al. 2007 | Seeding and fertilization | High | Plant cover and bare soil | Ineffective | 196 seeds/m2 (cool)  262 seeds/m2  (warm)  49 seeds/m2 (winter wheat) | Thick-spike wheatgrass  Idaho fescue  Snake River Wheatgrass, Sandberg bluegrass  Sheep fescue  Common yarrow  Common wheat | 11-17% | Northcentral Washington state |
| Rough 2007 | Seeding and scarification | Moderate to high | Sediment fence | Ineffective | **﻿**280 seeds m2, or  84 kg/ha | Spring oats  Winter triticale | 6% | Ponderosa pine in Colorado |
|  |  |  |  |  |  |  |  |  |
| Groen and Woods 2008 | Seeding | High severity | Sediment collector and plant cover | Ineffective | 9 kg/ha | Idaho fescue  Rough fescue  Bluebunch wheatgrass  Western wheatgrass Needle and thread grass  Green needlegrass  Slender wheatgrass | 4.8% | Spruce–fir forest in Northwestern Montana |
| Stella 2009 thesis | Seeding | High | Plant cover | Ineffective | 403 seeds /m2 | Bottlebrush squirreltail  Muttongrass  Purple locoweed  Blue grama  Scarlet gilia  Annual ryegrass  Common Wheat | 49-53% | Ponderosa pine in Arizona |
| Fernandez et al. 2010 | Seeding | Unknown | Sediment collection | Ineffective | 250 kg/ha | Annual ryegrass  Tall fescue  Orchard grass  Red fescue  White clover | 47% | Pardesoa hillslopes in NW Spain |
| Díaz-Raviña et al. 2012 | Seeding | Moderate to high | Sediment collection | Effective | 100 kg/ha | Rye | NA | Serra do Invernadoiro Natural Park in  Northwest Spain |
| Vega et al. 2015 | Seeding | Moderate to high | Sediment fence | Ineffective | 30 kg/ha | Annual ryegrass  Tall fescue | 35% | Shrub land in Northwest Spain |

TABLE 5. The plant species contained in the seed mixes proposed in BC seeding guidelines with their functional group and nativity, persistence, longevity, and erosion control efficacy

|  |  |  |  |
| --- | --- | --- | --- |
| Species | Functional group and nativity1 | Persistence (time) and longevity1 | Erosion control1 |
| Annual Ryegrass (*Lolium multiflorum*) | Agronomic grass  Biennial bunchgrass | Low and low (will only live 1-2 years) | Unknown |
| Crested Wheatgrass (*Agropyron cristatum*) | Agronomic grass  Perennial bunchgrass | High (can be 30 years+) and high  Both higher in dry areas | Moderate |
| Chewings Fescue (*Festuca rubra*) | Agronomic grass  Perennial bunchgrass | High and high | Moderate |
| Orchard grass (*Dactylis glomerata*) | Agronomic grass  Perennial bunchgrass | Moderate and moderate (2-6 years or longer) | Unknown |
| Timothy grass (*Phleum pratense*) | Agronomic grass  Perennial bunchgrass | Moderate and high (4-10 years) | Moderate |
| Slender wheatgrass (*Elymus trachycaulus*) | Native grass  Perennial bunchgrass | Moderate and low (3-4 years) | Moderate |
| Hard Fescue (*Festuca ovina*) | Agronomic grass  Perennial bunchgrass | High and high | Unknown |
| Redtop (*Agrostis gigantea*) | Agronomic grass  Perennial bunchgrass | High and high | High |
| Red clover (*Trifolium pratense*) | Agronomic legume  Tap-root short lived perennial | Low (2-3 years) and low (1-3 years) | Moderate |

1 Dob and Burton 2013

# **DISCUSSION**

Fire is an important natural disturbance that affects plant communities, wildlife, hydrology, and humans. With increasing WUI and climate change predictions, high severity fires impacts, and rehabilitation will increase across Western North America (Radeloff et al. 2018; Haider et al. 2019). Seeding is primarily used after high severity fires as rehabilitation option managers to mitigate post-fire erosion impacts. The seed mixes used in seeding are often non-native species and lack in long-term studies for their impacts. Results show that seeding is an ineffective tool for this objective and BC seed mixes for 2021/2022 contain problematic species. Therefore, selecting appropriate seed mixes and following up on results is important, and mulching may be the most effective erosion mitigation tool.

## **METHODS OF ASSESSING EROSION CONTROL**

As indicated in my results there are a variety of methods used to assess or evaluate erosion control and this can impact interpretation of results (Table 4). The methods used in the studies I assessed were vegetation cover percent and sediment collection fence. Vegetation cover is critical in reducing erosion from rainfall events by reducing water runoff and increasing infiltration (Marques et al. 2007; Zuazo and Pleguezuelo 2008). Therefore, plant cover is an important tool to measure erosion as well as species composition to monitor seeded species germination success. To reduce erosion ground cover of 60-70% is needed (Rough 2007; Robichaud et al. 2000). Sediment fences collect the actual amount of sediment eroded on hill slope, so they can quantify differences between treatment types and give more information than just vegetation cover. Sediment fences are a low-cost method to estimate hillslope erosion post-fire (Robichaud and Brown 2002) and are placed below the plots where erosion is occurring to determine the differences in sediment movement between treatment types. Using an erosion collection method like this is important as it determines actual quantities of sediment eroded instead of using only plant cover which is not a direct measure. Even though the studies I reviewed varied in methods used to assess erosion control; sediment fences and plant cover percent, they are still able to conclude efficacy, and the overall trend was seeding is ineffective.

## **SEEDING EFFECTIVENESS FOR EROSION CONTROL**

One of the main criteria that I examined in relation to erosion control was seeding. High severity fires remove vegetation, expose bare ground, and can produce a hydrophobic layer which greatly impacts infiltration rates thus leading to an increase of run-off and erosion (Elliot et al. 1996; Robichaud et al. 2009). Seeding is used in rehabilitation after high severity fires with intention to reduce the impact of post-fire erosion events. Timing is critical for post-fire rehabilitation because these areas are most susceptible the first year and erosion rates are highest the first 2 years after burned (Rough 2007). The studies I examined were all treated on moderate to high severity fires throughout the Western United States and Northwest Spain.

There are a variations of treatment types in the studies I reviewed including seeding, seeding and fertilization, seeding and scarification, and seeding and mulching. Treatment types, seeding rates, and seed mixes varied significantly across each study, and all concluded that they were ineffective at addressing erosion but Díaz-Raviña et al., (2012). Díaz-Raviña et al., (2012) stated seeding was effective because the seeded plots were significantly higher than the controls, but their results showed that seeding only reduced soil losses by 34-42% while mulched plots reduced 73-94%. They also did not collect vegetation or bare ground cover.

Across the studies I examined, higher seeding rates did not result in higher plant cover which makes direct comparisons difficult (Table 4). For example, Fernandez et al., (2010) seeded manually 250 kg/ha rate and had 47% cover and compared to Vega et al., (2015) who seeded manually at a 30 kg/ha rate and had 35% cover. All the studies I reviewed did not reach optimal ground cover of 60-70% and had an overall trend that the seeded plots had no significant differences between plant cover or sediment rates to control plots within in the first-year post-fire which is when erosion risk is highest. Stella (2009) and Fernandez et al. (2010) were close with 49-53% and 47% cover and seeded with the highest rates but, still concluded seeding ineffective as it did not reduce bare ground compared to control plots. Fernandez et al. (2010) had only 9.25% of seeded cover out of the total 47% total vegetation cover, thus seeding had a low contribution to total cover. Groen and Woods (2008), saw that ground cover was dominantly from natural regeneration rather than seeded species, and likewise, Robichaud et al., (2006), had 20% of cover from native vegetation. Rough (2006) revealed the use of scarification had actually increased sediment yields and seeding treatment did not increase vegetation cover (6%). Groen and Woods (2008) had lowest cover (4.8%) with no significant difference of mean sediment yield from seeded to control plots. They also, stated that lack of vegetation was due to lack of spring precipitation contributing to lack of vegetation cover.

These results reveal that seeding is unable to provide optimal cover percentages (60-70%) within the first-year post-fire or have significant difference to the control plots in terms of sediment losses. These are trends consistent across the studies I reviewed. The success of seeding heavily relies on weather factors and time. Favorable weather includes ample moisture for germination success and avoidance of heavy rainstorms that wash away seeds. Many studies saw that low ground cover was due to lack of germination (Wagenbrenner et al. 2006), or seeds washed away from heavy rainfall (Rough 2007), and drought conditions (Robichaud et al. 2006). These weather events can directly reduce germination success thus prevent seeded species to establish cover and mitigate erosion. Favorable and unfavorable weather events for seeding are hard to predict or avoid and therefore, using seeding for post-fire erosion has deemed ineffective across relevant high-quality studies. This is because we seed after the fire in the fall or spring and plants are unable to timely provide extensive root systems, high leaf cover, and litter which are factors that prevent erosion.

There are only few studies conducted in BC that have monitored the effectiveness of seeding. In Newman et al. (2016) the purpose of seeding was for forage replacement, and they concluded that the seeded sites compared to unseeded did not produce more forage. This was likely due to low mortality of native plants from the light to moderate burn severity on site causing them to regrow abundantly and not allowing seeded species to establish. A study done by Gardner et al., (2010) used seeding for erosion control and they found that seeded species cover was 17.6% out of total 77.8% cover during first year post-fire. Both studies showed that the seeded species contributed low amounts of cover.

## **BC SEED MIX**

In BC, post-fire seeding of agronomics species is sometimes used for erosion control, weed suppression, and forage replacement (Dob and Burton 2013). Range Branch (2021) recommends choosing species, when possible, that are non-native with low aggressiveness, and low persistence. Seeding with native species is rare due to the high expense and availability, therefore non-natives are chosen. When looking at the species in Table 5, only 1 out of the 9 species (Slender wheatgrass) is native with low persistence, 6 out of 9 species Crested wheatgrass (*Agropyron cristatum)*, chewing fescue (*Festuca rubra*), orchard grass (*Dactylis glomerata*), timothy grass (*Phleum pratense*), hard fescue (*Festuca ovina*), and redtop are all non-native agronomics with moderate to high persistence and longevity, and the other 2 species (annual ryegrass and red clover) have low persistence and longevity. Therefore, the BC seeding guidelines may not be technically adhering with their species selection recommendations.

When doing further research into the species ecology, the species chosen in BC post-fire seeding guidelines may not be targeting the specific issues stated in the objectives. Although these species are used widely over North America for erosion control and many other uses such as forage replacement, crop cover, and turf, their effectiveness in mitigating erosion post-fire lack data. The species of most concern in these mixes are crested wheatgrass and chewings fescue. Crested wheatgrass is in 2 out of 6 mixes and chewings is in 4 out of 6 mixes. Crested wheatgrass has historically been seeded post disturbances and have seen persisting up to 30 years (Zlatnik 1999). Its longevity, high competitiveness and extensive root system may impact the diversity and quality of native grasslands by competing for nutrients and space (Vaness 2007). Chewing fescue is extensively used as turf grass and erosion control because it produces rhizomes that can create a dense sod and for its high persistence and longevity (Dob and Burton 2013; UMCES). There is concern of species that create dense sods, such as Kentucky bluegrass (*Poa pratensis*), because they can alter natural ecosystem processes such as nutrient cycling and wildlife habitat (Toledo et al. 2014). Redtop is another species that produces rhizomes and can displace native vegetation and persists for many years. Orchard grass reduces persistence with high temperatures and has a low longevity of 2-4 years. Timothy grass has poor drought and heat tolerance and can persist up to 6 years (Bates date unknown). Annual ryegrass and red clover both have low persistence and quick establishment (Hall 1993; SARE outreach 2004; Clark 2007). Orchard grass and timothy grass are of less concern because they have moderate persistence. Literature agrees with Dob and Burton (2013) ecological definitions for orchard grass, Timothy grass, annual ryegrass, redtop, hard fescue, and red clover. If these mixes are seeded, monitoring of the effectiveness and long-term impacts should be conducted because, crested wheatgrass, chewings fescue, and other high persisting and long living species may impact native plant communities. Studies would be able to provide guidance in further management decisions in selecting appropriate seed mixes.

## **MANAGEMENT RECCOMENDATIONS**

The main focus of this literature review was to determine if seeding post-fire was effective in erosion control. My findings show that seeding after a moderate to high severity wildfire despite high seeding rates was ineffective in mitigating sediment loss during the first year post-fire. While the focus of my study was to inspect seeding efficacy, many of the studies also included mulching as a treatment type. The secondary focus of this review was to assess species in the BC seed mixes for post-fire erosion control. My findings show that many species specifically crested wheatgrass, chewings fescue, and other high persisting and long-lived species are most concerning for their possible impacts to native plant communities. When using these seed mixes studies should be conducted to ensure effectives and any environmental impacts are documented; they will contribute to aiding future management decisions.

Seeding has deemed not an effective mitigation measure for the objective to reduce erosion for multiple reasons. The main reason is that every study I examined was not able to achieve the recommended ground cover for effective erosion reduction. Drought conditions and heavy rainfall events may occur during the fall and spring when seeding takes place so, they are vulnerable to seeds washed away and failed germination. In addition to these reasons, seeding directly introduces non-native species, increases chance of invasive species introduction, and there is a lack of long-term studies of seeding effects on native plant communities. Therefore, seeding to prevent erosion on a hillslope post-fire has a high chance to be unsuccessful and inflict unknown long-term environmental impacts. Seeding is often considered an option for rehabilitation methods and when using it in extensive areas larger environmental issues may arise. In congruence with literature, I recommend using mulching instead of seeding for immediate erosion mitigation.

Mulching is another treatment option that is used to mitigate erosion post-high severity fires. Many of the studies that I reviewed for seeding also included mulching as a treatment type. Therefore, these studies have high-quality analysis, and their methods and results will be briefly described here.

Mulching reduces erosion by providing immediate ground cover that protects the soil from raindrop impact thus reduces erosion (Robichaud et al. 2013). The type of mulch includes, hydromulching, straw mulch, and dry wood-based mulches. Straw mulches can introduce non-natives if they are not purified out while wood mulches have a much lower chance, and hydromulches do not pose this threat (Robichaud et al. 2013). Wood-based and straw mulches have resulted in highest sediment reduction and hydromulching has significantly less efficacy that’s likely due to high decomposition rates (Girona-García et al. 2021). Similar to seeding, mulching must be 60-70% of ground cover but thin enough to allow plant seedlings to germinate (Robichaud et al. 2009). This treatment is highly successful and significantly different than seeding in reducing erosion rates during first year post-fire. Studies have shown a 73-94% reduction in sediment production within the first year post-fire (Groen and Woods 2008; Díaz-Raviña et al. 2012; Vega et al. 2015).

After all of my research and looking at literature results and recommendations, I recommend that seeding for erosion control post-high severity fires should be avoided and the use of mulch should be used instead due to its high efficacy. As well, if having to seed, the sites must be well planned and managed to consider ecosystem long-term health by selecting species that are not high persisting or long-lived and monitor future results.

# **LITERATURE CITED**

Badía D, Martí C. 2008. Fire and rainfall energy effects on soil erosion and runoff generation in semi-arid forested lands. Arid L Res Manag. 22(2):93–108. doi:10.1080/15324980801957721.

Baker WL. 2015. Are high-severity fires burning at much higher rates recently than historically in dry-forest landscapes of the western USA? PLoS One. 10(9):1–26. doi:10.1371/journal.pone.0136147.

Bates G. Tall Fescue, Orchard grass and timothy. Date unknown. Univ Tennessee Agric Ext Serv. [Accessed Mar 8 2022]. Available online: <https://extension.tennessee.edu/publications/Documents/SP434-E.pdf>.

[CCIS] Canadian council on invasive species. 2022. Invasive Species. [Accessed Mar 8 2022]. Available online: <https://canadainvasives.ca/invasive-species/>.

Clark A. 2007. Annual ryegrass. Manag Cover Crop Profitab.:74–77. [Accessed Mar 8 2022]. Available online: <https://mccc.msu.edu/wp-content/uploads/2016/09/ManagingCoverCropsProfitably_AnnualRyegrass.pdf>.

Curran MP, Chapman B, Hope G, Scott DF, Program FS. 2006. Large-scale erosion and flooding after wildfires: Understanding the soil conditions. Tech Rep 030.

Díaz-Raviña M, Martín A, Barreiro A, Lombao A, Iglesias L, Díaz-Fierros F, Carballas T. 2012. Mulching and seeding treatments for post-fire soil stabilisation in NW Spain: Short-term effects and effectiveness. Geoderma. 191:31–39. doi:https://doi.org/10.1016/j.geoderma.2012.01.003.

Elliot WJ, Page-Dumroese D, Robichaud PR. 1996. The effects of forest management on erosion and soil productivity. Soil Qual Soil Eros. doi:10.1201/9780203739266-12.

Fernández C, Vega JA, Jiménez E, Vieira DCS, Merino A, Ferreiro A, Fonturbel T. 2012. Seeding and mulching + seeding effects on post-fire runoff, soil erosion and species diversity in Galicia (NW Spain). L Degrad \& Dev. 23(2):150–156. doi:https://doi.org/10.1002/ldr.1064.

Flannigan M., Stocks B., Wotton B. 2000. Climate change and forest fire. Sci Total Environ. 262(3):221–229.

Flannigan M, Cantin AS, de Groot WJ, Wotton M, Newbery A, Gowman LM. 2013. Global wildland fire season severity in the 21st century. For Ecol Manage. 294:54–61. doi.org/10.1016/j.foreco.2012.10.022.

[FPB] Forest Practices Board. 2004. Post-fire Site Rehabilitation Special Investigation: Interim Report. <https://www.bcfpb.ca/reports-publications/reports/post-fire-site-rehabilitation-special-investigation-interim-report/>

Groen AH, Woods SW. 2008. Effectiveness of aerial seeding and straw mulch for reducing post-wildfire erosion, north-western Montana, USA. Int J Wildl Fire. 17(5):559–571. doi:10.1071/WF07062.

Haider W, Knowler D, Trenholm R, Moore J, Bradshaw P, Lertzman K. 2019. Climate change, increasing forest fire incidence, and the value of visibility: Evidence from British Columbia, Canada. Can J For Res. 49(10):1242–1255. doi:10.1139/cjfr-2018-0309.

Hall MH. 1993. Red clover. Penn State Extension. [Accessed Mar 8 2022]. Available online: <https://extension.psu.edu/red-clover>.

Halofsky JE, Peterson DL, Harvey BJ. 2020. Changing wildfire, changing forests: the effects of climate change on fire regimes and vegetation in the Pacific Northwest, USA. Fire Ecol. 16(1):4. doi:10.1186/s42408-019-0062-8.

[ICT] Indigenous corporate training INC. 2019. Indigenous fire management and traditional knowledge. [Accessed Mar 8 2022]. Available online: https://www.ictinc.ca/blog/indigenous-fire-management-and-traditional-knowledge.

Johansen MP, Hakonson TE, Breshears DD. 2001. Post-fire runoff and erosion from rainfall simulation: Contrasting forests with shrublands and grasslands. Hydrol Process. 15(15):2953–2965. doi:10.1002/hyp.384.

Lyon LJ, Huff MH, Hooper RG, Telfer ES, Schreiner DS, Kapler Smith J. 2000. Wildland fire in ecosystems: effects of fire on fauna. Rocky Mountain Research Station. 1:2-4.

MacDonald DB, Hudson G. 2012. The genocide question and Indian residential schools in Canada. Can J Polit Sci. 45(2):427–449. doi:10.1017/S000842391200039X.

Marques MJ, Bienes R, Jiménez L, Pérez-Rodríguez R. 2007. Effect of vegetal cover on runoff and soil erosion under light intensity events. Rainfall simulation over USLE plots. Sci Total Environ. 378(1):161–165. http://10.0.3.248/j.scitotenv.2007.01.043.

McLauchlan KK, Higuera PE, Miesel J, Rogers BM, Schweitzer J, Shuman JK, Tepley AJ, Varner JM, Veblen TT, Adalsteinsson SA, et al. 2020. Fire as a fundamental ecological process: Research advances and frontiers. J Ecol. 108(5):2047–2069. doi.org/10.1111/1365-2745.13403.

Neary DG, Ryan KC, DeBano LF, Beyers JL, Brown JK, Busse MD, Elliot LF, Ffolliott PF, Jacoby GR, Knoepp JD, et al. 2005. Wildland fire in ecosystems: effects of fire on soil and water. Rocky Mt Res Stn. 4:1–235. doi:10.1016/j.catena.2008.03.011.

Peterson DW, Dodson EK, Harrod RJ. 2007. Assessing the effectiveness of seeding and fertilization treatments for reducing erosion potential following severe wildfires. Dep Agric For Serv Rocky Mt Res Station.:465–474.

Radeloff VC, Helmers DP, Anu Kramer H, Mockrin MH, Alexandre PM, Bar-Massada A, Butsic V, Hawbaker TJ, Martinuzzi S, Syphard AD, et al. 2018. Rapid growth of the US wildland-urban interface raises wildfire risk. Proc Natl Acad Sci USA. 115(13):3314–3319. doi:10.1073/pnas.1718850115.

Robichaud PR, Beyers JL, Neary DG. 2000. Evaluating the effectiveness of postfire rehabilitation treatments. General Technical Report RMRS-GTR-63.

Robichaud PR, Brown PR. 2002. Silt fences: an economical technique for measuring hill slope erosion. General Technical Report RMRS-GTR-94.

Robichaud PR, Lillybridge TR, Wagenbrenner JW. 2006. Effects of postfire seeding and fertilizing on hillslope erosion in north-central Washington, USA. Catena. 67(1):56–67. doi:10.1016/j.catena.2006.03.001.

Robichaud PR, Lewis SA, Brown RE, Ashmun LE. 2009. Emergency post-fire rehabilitation treatment effects on burned area ecology and long-term restoration. Fire Ecol. 5(1):115–128. doi:10.4996/fireecology.0501115.

Robichaud PR, Lewis SA, Wagenbrenner JW, Ashmun LE, Brown RE. 2013. Post-fire mulching for runoff and erosion mitigation. Part I: Effectiveness at reducing hillslope erosion rates. Catena. 105:75–92. doi:10.1016/j.catena.2012.11.015.

Rough D. 2007. Effectiveness of rehabilitation treatments in reducing post-fire erosion after the Hayman and Schoonover fires, Colorado front range. Thesis. Colorado State University.

Santín C, Doerr SH. 2016. Fire effects on soils: the human dimension. The Royal Society. 371(1696). doi:10.1098/rstb.2015.0171.

SARE outreach. 2007. Managing cover crops profitably, third edition. Sustain Agric Res Educ. :159–164. [Accessed Mar 8 2022]. Available online: <https://www.sare.org/resources/managing-cover-crops-profitably-3rd-edition/>

Sarris D, Koutsias N. 2014. Ecological adaptations of plants to drought influencing the recent fire regime in the Mediterranean. Agric For Meteorol. 184:158–169. [doi.org/10.1016/j.agrformet.2013.09.002](https://doi.org/10.1016/j.agrformet.2013.09.002)

Stella KA. 2009. Effects and effectiveness of seeding following high-severity wildfires in northern Arizona ponderosa pine forests. Thesis. Northern Arizona University.

Toledo D, Sanderson M, Spaeth K, Hendrickson J, Printz J. 2014. Extent of Kentucky bluegrass and its effect on native plant species diversity and ecosystem services in the northern great plains of the United States. Invasive Plant Sci Manag. 7(4):543–552. doi:10.1614/ipsm-d-14-00029.1.

Tzembelicos, Andrew; Erhardt, Austen; de Faye, Bob; Guy, Brian; Kent, Christian; Bedwell, Curtis; Wall, Dale; Vermeulen, Darcy; Forsdick, Geoff; Farson, Hilary; Paulus, Irene; Enns, Jan; Stewart, Jane; Fraser, Jennifer et al. 2018. Addressing the new normal: 21st century disaster management in British Columbia. BC Government.

Vega JA, Fernández C, Fonturbel T. 2015. Comparing the effectiveness of seeding and mulching+seeding in reducing soil erosion after a high severity fire in Galicia (NW Spain). Ecol Eng. 74:206–212. doi:10.1016/j.ecoleng.2014.10.019.

Vaness BM, Wilson SD. 2007. Impact and management of crested wheatgrass (*Agropyron cristatum*) in the northern Great Plains. Can J Plant Sci. 87(5):1023–1028. doi:10.4141/CJPS07120.

Wagenbrenner JW, MacDonald LH, Rough D. 2006. Effectiveness of three post-fire rehabilitation treatments in the Colorado Front Range. Hydrol Process. 20(14):2989–3006. doi:10.1002/hyp.6146.

Zlatnik E. 1999. Species: *Agropyron cristatum*. Fire Eff Inf Syst Dep Agric For Serv Rocky Mt Res Station Fire Sci Lab. [Accessed Mar 8 2022]. Available online: <https://www.fs.fed.us/database/feis/plants/graminoid/agrcri/all.html#COVER%20VALUE>

Zuazo V, Pleguezuelo C. 2008. Soil-erosion and runoff prevention by plant covers. A review. Agron Sustain Dev (EPD Sci. 28(1):65–86. doi:10.1016/j.pmpp.2018.05.009.

# **APPENDICES**

## **APPENDIX 1. PLANT SPECIES COMMON AND SCIENTIFIC NAMES**

Table A 1. List of common and scientific names of all plant species listed in this paper

|  |  |
| --- | --- |
| **Common name** | **Scientific name** |
| Annual ryegrass | *Lolium multiflorum* |
| Blue grama | *Bouteloua gracilis* |
| Bluebunch wheatgrass | *Agropyrum spicatum* |
| Bottlebrush squirreltail | *Elymus elymoides* |
| Common wheat | *Triticum aestivum* |
| Common yarrow | *Achillea millefolium* |
| Crested wheatgrass | *Agropyron cristatum* |
| Green needlegrass | *Nassella viridula* |
| Hard fescue | *Festuca ovina* |
| Idaho fescue | *Festuca idahoensis* |
| Mountain brome | *Bromus marginatus* |
| Muttongrass | *Poa fendleriana* |
| Needle and thread grass | *Hesperostipa comata* |
| Orchard grass | *Dactylis glomerata* |
| Purple locoweed | *Oxytropis lambertii* |
| Rough fescue | *Festuca campestris* |
| Red clover | *Trifolium pratense* |
| Red fescue / Chewings fescue | *Festuca rubra* |
| Redtop | *Agrostis gigantea* |
| Rye | *Secale cereale* |
| Sandbergs bluegrass | *Poa secunda* |
| Scarlet gilia | *Ipomopsis aggregata* |
| Sheep fescue | *Festuca ovina* |
| Slender wheatgrass | *Elymus trachycaulus* |
| Snake river wheatgrass | *Elymus wawawaiensis* |
| Spring oats | *Avena sativa* |
| Tall fescue | *Festuca arundinacea* |
| Thick-spike wheatgrass | *Elymus lanceolatus* |
| Timothy grass | *Phleum pratense* |
| Western wheatgrass | Agropyron smithii |
| White clover | Trifolium repens |
| White winter wheat | Triticum estivum |
| Winter triticale | Triticosecale rimpaui |

## **APPENDIX 2. REFERENCES INCLUDED IN THE REVIEW (WITH QUALITY OF EVIDENCE RATINGS)**

Díaz-Raviña M, Martín A, Barreiro A, Lombao A, Iglesias L, Díaz-Fierros F, Carballas T. 2012. Mulching and seeding treatments for post-fire soil stabilisation in NW Spain: Short-term effects and effectiveness. Geoderma. 191:31–39. doi:https://doi.org/10.1016/j.geoderma.2012.01.003. **Highest**

Fernández C, Vega JA, Jiménez E, Vieira DCS, Merino A, Ferreiro A, Fonturbel T. 2012. Seeding and mulching + seeding effects on post-fire runoff, soil erosion and species diversity in Galicia (NW Spain). L Degrad \& Dev. 23(2):150–156. doi:https://doi.org/10.1002/ldr.1064. **High**

Groen AH, Woods SW. 2008. Effectiveness of aerial seeding and straw mulch for reducing post-wildfire erosion, north-western Montana, USA. Int J Wildl Fire. 17(5):559–571. doi:10.1071/WF07062. **Highest**

Peterson DW, Dodson EK, Harrod RJ. 2007. Assessing the effectiveness of seeding and fertilization treatments for reducing erosion potential following severe wildfires. Dep Agric For Serv Rocky Mt Res Station.:465–474. **Highest**

Stella, K.A., 2009. Effects and Effectiveness of Seeding Following High-Severity Wildfires in Northern Arizona Ponderosa Pine Forests. M.S. Thesis. Northern Arizona University. **Highest**

Robichaud PR, Lillybridge TR, Wagenbrenner JW. 2006. Effects of postfire seeding and fertilizing on hillslope erosion in north-central Washington, USA. Catena. 67(1):56–67. doi:10.1016/j.catena.2006.03.001. **Highest**

Rough D. 2007. Effectiveness of rehabilitation treatments in reducing post-fire erosion after the hayman and schoonover fires, colorado front range. M.S. Thesis. Colorado State University. **Highest**

Wagenbrenner JW, MacDonald LH, Rough D. 2006. Effectiveness of three post-fire rehabilitation treatments in the Colorado Front Range. Hydrol Process. 20(14):2989–3006. doi:10.1002/hyp.6146. **High**

Vega JA, Fernández C, Fonturbel T. 2015. Comparing the effectiveness of seeding and mulching+seeding in reducing soil erosion after a high severity fire in Galicia (NW Spain). Ecol Eng. 74:206–212. doi:10.1016/j.ecoleng.2014.10.019. **Highest**