Burning Questions: Effects of restoration burning on selected PP and IDF zone ecosystems in the Southern Interior Rocky Mountain Trench

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March 2018

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ACKNOWLEDGEMENTS

This project was funded by the Forest Enhancement Society of British Columbia (FESBC) and the Rocky Mountain Trench Natural Resources Society. The following individuals are thanked for their contribution of time and expertise at the initiation of the project:

- Randy Harris – East Kootenay Invasive Species Council
- Jeff Allen – Self-employed consultant
- Gail Berg – Self-employed consultant
- Dan Murphy – Rocky Mountain Trench Natural Resources Society
- Tim Ross – Self-employed consultant
- Steve Byford – Grassland and Rangeland Enhancement Program
- Emily Nilsen – Columbia Basin Trust
- Juliet Craig – Kootenay Conservation Program

FLNRO
- Paul Rasmussen
- Al Neal
- Ray Morello
- Mike Knapik
- Mike Morrow
- Art Westerhaug
- Allana Oestreich
- Brian Watson
- Larry Ingham
- Shawna Larade
- Kenric Walburger
- Ariana McKay

MOE
- Amanda Weber-Roy
- Albert Chirico

Parks Canada
- Jed Cochrane
- Charlie McLellan

The original collection of data and reporting were funded by the following agencies

- Rocky Mountain Trench Ecosystem Restoration Program
- FLNRO
- Columbia Basin Trust Environmental Initiatives Program
- BC Hydro Fish and Wildlife Compensation Program
- Rocky Mountain Trench Natural Resources Society

- Parks Canada Agency. Redstreak data. Reproduced with the permission of Parks Canada Agency
- Forest Renewal BC
- Forest Investment Account – Forest Science Program of the BC Ministry of Forests and Range.

Thanks to Sybille Haeussler and Julia Chandler who provided valuable statistical support. This product has been produced for Forest Enhancement Society of British Columbia based (in part) on data provided by Parks Canada Agency.

SUMMARY

An analysis of understory vegetation responses of 8 primary and 21 secondary treatment units in the East Kootenay Rocky Mountain Trench was conducted primarily using plant species presence/absence as a measure of abundance. Presence/absence is less prone to weather-related fluctuations compared to plant cover and is potentially more sensitive to incipient population increases because a one-year-old plant is given the same importance as a fully-grown plant.

Prescribed fire increased the amount of exposed mineral soil to some degree at all sites. Exposed soil creates conditions suitable for the establishment of plant seedlings, either from previously buried seed or seed transported from off-site sources. Exposed soil is therefore necessary for the establishment of new plants of desirable species, but also increases the risk of infestation by non-native species. Most treatment units examined, including unburned control sites, had short-term increases of non-native plant species. Many of these responses could be characterized as spikes, with non-native species returning to pre-fire levels within a brief period. A broader summary over 21 sites showed that the most common invasive plants that continue to increase after prescribed fire are of little or no concern (e.g., dandelion, black medic, yellow salsify). There were two FRPA-listed invasive plants (St. John’s wort and sulphur cinquefoil) that increased at a few sites at low levels that are, nonetheless, cause for concern. They occur throughout the southern half of the Rocky Mountain Trench, are not unexpected at disturbed sites and should be specifically targeted for monitoring at future prescribed burn sites.

Objectives regarding promotion of grassland plant communities had not yet been achieved, even 14 – 17 years post-fire. Overall, it appears that burning for the objective of increasing bunchgrass has been more successful in the IDF zone than in the PP zone. Although the trends may be promising at some sites, the percent cover of late-seral bunchgrass is far short of the reference condition. Even under ideal conditions it may require 20 or more years for late seral bunchgrass species to become dominant. Grazing by livestock and wild ungulates may be interfering with the establishment and growth of these species.

CONTENTS

1.0 INTRODUCTION

Prescribed fire is a land management practice that intentionally applies fire to vegetation and is conducted under desired conditions to meet specific objectives. In the East Kootenay Rocky Mountain Trench of BC prescribed fire has been utilized as one of the tools to achieve ecosystem restoration objectives within dry forests for almost 20 years. Ecosystem restoration burns usually occur two years after thinning of the forest stand, during April when plants are at an early stage of development (Bond et al. 2013). Some common objectives of burning include:

- Reducing wildfire hazard around communities and across the landscape (Bond et al. 2013)
- Reducing slash, surface litter and duff (Page 2005)
- Re-introduction of fire as a natural process (Crowley and Gall 2011)
- Maintaining or increasing fire-adapted native understory vegetation (Page 2005)
- Increasing native species cover (LLYK Fire and Vegetation Management Section 2009).

Some uncertainty exists regarding whether prescribed fire as currently practised is fully achieving all objectives (Bond et al. 2013).

Patterns of understory vegetation succession following prescribed fire in North American forests have been extensively studied and synthesized (Willms et al. 2017, Bartuszevige and Kennedy 2009, Brown and Smith 2000). More locally, Wikeem and Strang (1983) and Page (2014) provide reviews of understory response to prescribed fire for BC and the Rocky Mountain Trench, respectively. A common conclusion among the reviews is that the response of understory vegetation to fire is highly variable. This is not surprising given the breadth of ecosystems considered in some of the reviews, however, even those focussed at the biogeoclimatic zone level report variable results (Wikeem and Strang 1983, Page 2014). The major causes of this variation are likely from differences in:

1) Weather conditions during the fire that affect fire behaviour (Turner and Lawson 1978)

2) Weather conditions in the years following fire that affect plant response

3) Fuel amount, type and distribution that affect fire behaviour (Agee and Skinner 2005)

4) Topography such as aspect and degree of slope that affect fire behaviour

5) Pre-fire plant species composition and abundance including seedbanks and dormant propagules

6) Proximity, species composition, and amount of off-site plant propagules

7) Post-fire management including levels of livestock and ungulate grazing.

A second common conclusion among the reviews was that non-native plant species increased, at least to some extent, following fire. Prescribed fire is a disturbance that results in an immediate increase of available resources, with the amount and type of resources dependent on the severity of the fire. This occurs because of mortality of existing vegetation and physical and chemical changes on the forest floor, mostly because of the combustion process (e.g., Gundale et al. 2005). The increase of resources such as nutrients, soil moisture, light and mineral soil seedbed provide an opportunity for increases of existing plants or colonization by new species (Bartuszevige and Kennedy 2009). The first to take advantage of the increased resources will be plant species with the following characteristics:

1) plants that can re-sprout from underground parts;

2) plants that reproduce by long distance wind-blown seed;

3) shade intolerant plants that store seed in the soil (Mah 2000); and

4) plants with a high investment in seed production.

Despite the potential for increases of non-native species, most post-fire studies report low levels, or levels that decline with time.

1.1 Study Objectives

The objective of this study was to answer key client-based questions regarding the use of prescribed fire in Southern Interior BC. Our team contacted 26 decision makers, resource managers and experts in the provincial government and other agencies to determine priorities for information synthesis related to prescribed fire and availability of information. We determined that the highest priority needs that we could address given our time, resources and expertise were those related to determining the effectiveness of prescribed fire in ensuring management objectives related to ecosystem functioning. Our initial focus was on analysing the ecosystem restoration burning monitoring program data from the Rocky

Mountain Trench since there is an active burning program in that area. The following questions were identified as being of priority to resource managers and decision makers while also being answerable within the constraints of the project:

1) Management objectives - To what extent is restoration burning achieving objectives related to ecosystem restoration, forage production, and wildlife habitat and what is the reforestation response?
2) Invasive species - What effect does burning have on establishment and growth of invasive species – particularly in the southern interior? How does soil disturbance and compaction and damage to vegetation in the pre-burn phase due to grazing and slashing effect invasive species establishment and growth post-burn?
3) Tree regeneration - What effect does burning have on the re-establishment of tree seedlings? Can it lead to enhanced ingrowth due to enhance forage quality/quantity and therefore an increase in the presence of animals that trample seeds into the forest floor thereby enhancing conifer establishment success beyond desirable levels?
4) Ecosystem specific restoration burning prescriptions – How do different ecosystems respond to burning?

Preliminary examination of the datasets refined the set of questions to:

1) Management objectives - To what extent is restoration burning achieving objectives related to:
    a. Increasing bunchgrass abundance (value for livestock and ungulate forage, value as an indicator of grassland habitat for wildlife)
    b. Increasing abundance of late seral bunchgrass (value for livestock and ungulate forage, value as an indicator of grassland habitat for wildlife)
2) Invasive species - What effect does burning have on mineral soil exposure and establishment and abundance of non-native species (including invasive species)? How does soil disturbance in the pre-burn phase due to harvesting affect the establishment and increase in abundance of non-native species (including invasive species) post-burn?
3) Tree regeneration - What effect does burning have on the abundance of tree seedlings in the short- and medium-term?
4) Ecosystem specific restoration burning prescriptions – Is there a difference in plant species composition response on IDF versus PP sites?

2.0 BACKGROUND AND METHODOLOGY

2.1 Selection of datasets

Datasets were obtained from the Rocky Mountain Trench Ecosystem Restoration Program (RMTERP) database, Parks Canada Agency, and FLNRO for the low elevation area between Radium Hot Springs and the U.S.A. border. The RMTERP database consists of 24 ecosystem restoration monitoring sites sampled between 1998–2016 in the Rocky Mountain Trench (Page 2014). These datasets were examined for their potential use in answering our set of questions (Table 1).

Our criteria for selection of datasets suitable for data analysis were:

1. Broadcast prescribed fire utilized or sites suitable for use as a control
2. A minimum of three points of sampling over time including:
    a. Sampling after harvest but before fire so that the effect of fire could be isolated from the effect of harvest
    b. Post burn sampling during the year of fire or shortly afterward
    c. At least one additional sample taken in a subsequent post-fire year
3. Sampling design that consisted of multiple macroplots[1] within a treatment unit, each with macroplot(s) containing nested subplots.

These criteria resulted in the selection of 19 treatment units for further analysis, including 4 primary sites (Fig. 1) which included 8 primary treatment units (Table 1) used for quantitative analyses and 11 secondary treatment units. Each treatment unit received a different treatment (e.g., burned, logged and burned, control). The secondary treatment units were used for less rigorous narrative syntheses.

[1] **Definitions:**

Site – a geographic location within which a study or monitoring trial was conducted. Sites may contain more than one treatment unit.

Treatment unit – an area, usually many hectares, that received a certain treatment (e.g., burned, unburned, logged and burned, control). Treatment units contain one or more macroplots.

Macroplot - an area or set of transect(s) that was subsampled using multiple subplots.

Table 1. Timing of harvest, prescribed fire treatments and sampling for treatment units examined in this study. Numbers indicate total macroplots sampled for that year.

Treatment unit	Burn treatment	Timing of treatments (yr) in relation to the first prescribed fire (0=year burned)																									
		-8	**-7**	**-6**	**-5**	**-4**	**-3**	**-2**	**-1**	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**
Gina Lake B	Burned 2010	4									4																
Gina Lake UB	Unburned	11									11																
Redstreak B5/9*	Burned 05/09								21	21	7			19							18						
Redstreak UB*	Unburned								8	8	8			8								.					
Rocks B	Burned 2006					7					7		7						7								
Rocks UB	Unburned					8					8		8						8								
Miller Road HB*	Burned 1998							10	10	10	10	10												10			
Miller Road B*	Burned 1998							10	10	10	10	10												10			
Miller Road H*	Burned 2008							10	10	10	10	10												10			
Miller Road C*	Unburned							10	10	10	10	10												10			
Wolf Pasture*	Burned 2004				18	18	18		18	18	18	18															
Sheep Creek N*	Unburned				14	14	14		14	14	14	14															
Fontaine N B	Burned 2000								26	24				25					13								
Fontaine N C	Burned 2000								26	24				25					13								
Burk	Burned 2004				2	2	2				2						2					2					
Rushmere	Burned 2000					2			2		2				2						2					2	
Johnson Lake	Burned 1999							4		4	4	4				4											4
Springbrook	Burned 99/05							2		2	2	2				2						2					2
Premier Sheep	Burned 1999							2		2	2	2				2						2					2

Log Slash Burn

*Primary treatment units used for quantitative analyses

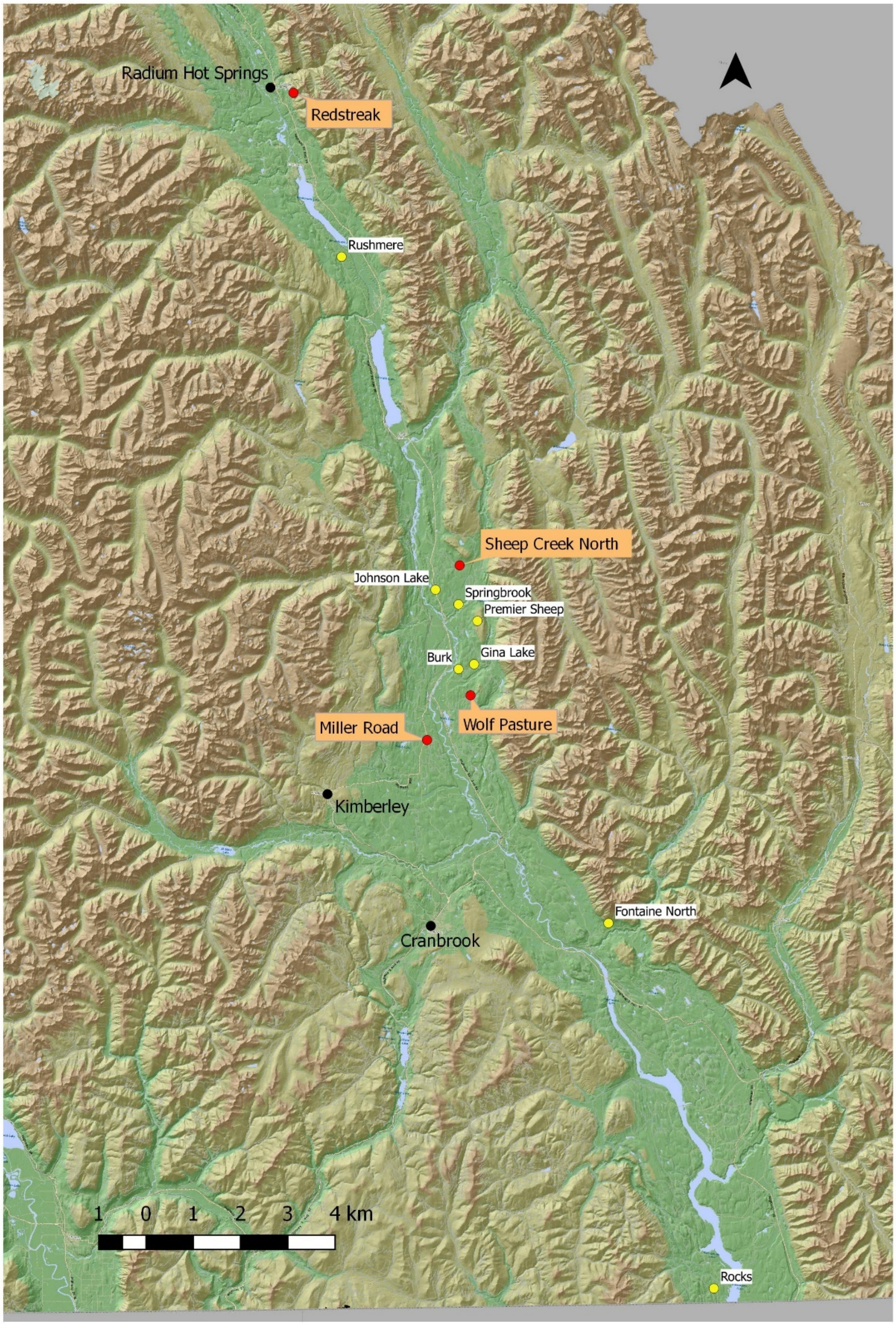


Figure 1. Locations of primary (red markers) and secondary (yellow markers) treatment units.

2.2 Sampling methods

Sampling methods varied by site, sometimes within site by year, and sometimes by treatment unit within site (Table A-2). A common element was that canopy cover of plant species and cover of substrates within subplots was usually sampled using Daubenmire frames (Daubenmire 1959). Many sites used the sampling protocol recommended in Machmer et al. (2002).

2.3 Data analysis

A count of presence/absence of individual plant species, plant functional groups, and mineral soil exposure was calculated for each macroplot in each year for all treatment units that met the study criteria. A presence/absence count is a measure of relative abundance that is closely related to percent plant frequency (e.g., Youngblood et al. 2006). Presence is calculated by totalling the number of quadrats or subsamples within a macroplot that contain the plant species. For the purposes of our study presence/absence measures have a few important advantages over percent cover including:

1) Presence/absence is relatively insensitive to seasonal and weather-related changes in plant abundance (Despain et al. 1991). Its use minimizes the nuisance effect of years with abnormally high or low precipitation that can cause a large variation in percent cover.
2) Presence/absence is also relatively insensitive to seasonal grazing at levels that do not cause plant mortality or result in increases of invasive species. This is important when considering that moderate levels of livestock and ungulate grazing can reduce percent cover while percent frequency will remain largely unchanged. Both livestock and ungulate grazing are prevalent on most of the study sites but the quantification of the degree of grazing is poorly known at the site level.
3) Presence/absence is potentially more sensitive to incipient plant population increases because a one-year-old plant is given the same importance as a fully-grown plant.
4) When data sets were initially examined using percent cover, it was found that most were positively skewed and often could not be transformed to a normal distribution. Presence/absence is considered binary data, which allows testing based on other distributions.

Macroplot numbers varied by treatment unit and sometimes by year of sampling and ranged from 7 – 21 (Table 1). The plant species and functional groups examined were determined by our set of questions and their importance to the objectives of ecosystem restoration program in the Rocky Mountain Trench and included:

1) Non-native plant species including agronomic and invasive species (see Appendix A-2)
2) Native bunchgrasses as indicators of grassland habitat and with value as forage for wildlife and ungulates (Appendix A-2)
3) Late seral bunchgrasses as indicators of healthy grasslands and high value forage. (Appendix A-2)

Presence of exposed mineral soil was used as an indicator of risk for increase in invasive plant species.

Short-term response curves

We used a model selection approach to test a set of alternative hypotheses related to our questions (Table 2) and we selected the best model based on the Akaike information criterion (AIC) (e.g., Burnham et al. 2011). Models were tested individually on each treatment unit due to differences in experimental design across sites and sometimes within site (Table 1). Design differences such as year of fire, number of fires, spacing of sampling points over time, and differences in pre-fire harvesting did not allow a meaningful analysis that included all sites/treatment units. Only short-term (pre-fire, year of fire, and 1-2 years post-fire) models were tested with this approach.

Mixed effects logistical regression was used to test for changes in presence/absence over time for species groups and exposed mineral soil. This method is appropriate for binary data from longitudinal studies where repeated measurement of the same plots over time violates the assumption of independence (Yee and Dirnbock 2008). The glmer function (Bates et al. 2017) of the R Project for Statistical Computing (R Core Team 2017) was used for all analyses. The logit link option was used and macroplot was specified as a random effect.

Table 2. Alternative models for species group or soil response to fire applied short-term scales.

Model #	Description of Model Components	Formula
1	Null model: species group/soil is resistant to fire	$Y = a$
2	Linear model: species group/soil increases or decreases with fire	$Y = a + t$
3	Quadratic model: species group/soil is resilient following fire	$Y = a + t + t^2$

Long-term changes

We used Friedman ranked sum tests with Nemenyi post-hoc pairwise multiple comparison test for significant differences ($p < 0.05$) of presence/absence counts among years with large gaps in time (Mangiafico 2018). Analyses were conducted by treatment unit and therefore the design is unreplicated. Macroplot was used as the blocking factor to account for repeated measures nature of the design. The R Project for Statistical Computing (R Core Team 2017) was used for all analyses.

Patterns of plant species associations following fire

A rank-based ordination was employed to examine individual treatment units for common patterns of plant species associations following prescribed fire. We used Non-metric Multidimensional Scaling (NMDS) with a Bray-Curtis dissimilarity index and Wisconsin double standardization on plant species presence/absence counts. All analyses were conducted using the metaMDS function of the vegan package (Oksanen et al. 2018) in R Project for Statistical Computing (R Core Team 2017).

Narrative synthesis

We used a narrative review approach (e.g., Bartuszevige and Kennedy 2009) to synthesize the results of our quantitative tests (primary sites) and summaries from treatment units that were not analysed (secondary sites) (Table 2). This approach allowed us to describe trends and summarize common responses but did not allow for the calculation of overall magnitude of effects or predictive models. Mean presence/absence of plant species of interest on individual treatment units were examined over time and the response was assigned to one of six categories:

- Increased
- Decreased then increased,
- Flat (no change over time),
- Decreased,
- Increased then decreased, and
- Lost (not recorded at last sampling)

Response of percent plant cover was used for five treatment units where plant presence/absence data was not calculable because sub-plot data were not available.

3.0 RESULTS

3.1 What effect does burning have on mineral soil exposure and establishment and abundance of non-native species?

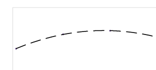
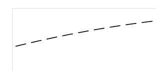
3.1.1 Short-term

Exposed mineral soil as a risk indicator

Six treatment units were examined individually to determine the response of exposed mineral soil to prescribed burning. Three treatment units were used as unburned controls. These were monitored in the same years as the corresponding burned treatment units within the same site. For example, Miller Harvest was sampled in 1997, 1998, 1999 and 2000 as were all Miller site treatment units. Sheep Creek North was used as a control for Wolf Pasture, but it should be noted that it is 16 km to the north at a slightly different elevation (914 m vs 882 m) in a different BEC zone. Exposed mineral soil was not sampled immediately post burn at Redstreak so it was not included in the analysis. All reported responses were measured after any harvest/slash treatment but before the prescribed burn

Levels of exposed mineral soil did not change at two treatment units considered as controls and dropped slightly before increasing to previous levels at the third control site (Table 3). In contrast, in two burned treatment units mineral soil exposure increases initially followed by a decline post-fire to levels somewhat higher than observed pre-fire. In the third burned treatment unit (Miller Harvest Burn) mineral soil exposure levels increased over time.

Table 3. Short term response of exposed mineral soil following prescribed fire. Years tested always included the year before the prescribed fire, the year of prescribed fire, and one or two post-fire years.

	Treatment		Fire Weather Codes and Indices			BEC unit[4]	Response Period (yr)	Response Curve
Treatment unit	**Harvest**	**Burn/Year**	**DMC[1]**	**DC[2]**	**FWI[3]**			
Sheep Creek N	yes	no burn	NA	NA	NA	IDFdm2	4	
Wolf Pasture	yes	2004	44	399	22	PPdh2	4	
Miller - Burn	no	1998	40/27	360/240	20/0	PPdh2	4	
Miller - Harvest Burn	yes	1998	40/27	360/240	20/0	PPdh2	4	
Miller - Harvest	yes	no burn	NA	NA	NA	PPdh2	4	
Miller - Control	no	no burn	NA	NA	NA	PPdh2	4	

[1]DMC – "The Duff Moisture Code (DMC) is a numeric rating of the average moisture content of loosely compacted organic layers of moderate depth. This code gives an indication of fuel consumption in moderate duff layers and medium-size woody material." (Natural Resources Canada, 2018)
[2]DC – "The Drought Code (DC) is a numeric rating of the average moisture content of deep, compact organic layers. This code is a useful indicator of seasonal drought effects on forest fuels and the amount of smouldering in deep duff layers and large logs." (Natural Resources Canada, 2018)
[3]FWI – "The Fire Weather Index (FWI) is a numeric rating of fire intensity. It combines the Initial Spread Index and the Buildup Index. It is suitable as a general index of fire danger throughout the forested areas of Canada." (Natural Resources Canada, 2018)
[4]BEC unit – Biogeoclimatic Ecosystem Classification variant (Braumandl and Curran 1992).

These results clearly indicate that prescribed burning in the PPdh2 at Drought Codes of 360 and 399 led to short-term increases in exposed soil. This occurred at two sites that were harvested then burned and at one that was just burned (Table 3).

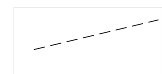
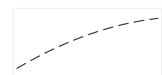
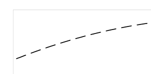
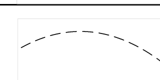
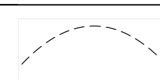
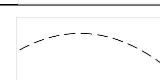
Changes in the levels of non-native plant species

The same six treatment units were used to determine the response of non-native plant species to prescribed burning. Two additional treatment units from the Redstreak site were added for these analyses. Unlike the responses of mineral soil exposure on unburned treatment units, the presence of non-native plant species increased (at least initially) on all unburned treatment units (Table 4). Two unburned Miller treatment units showed initial increases in abundance of non-native plant species, and then a decline to levels slightly lower levels than those found pre-fire. Abundance continued to increase on the unburned Redstreak and Sheep Creek North sites, indicating the potential for longer-term increase in non-native species. Increases in non-native species at harvested but unburned treatment units suggest that the harvesting treatment predisposes sites to invasion by non-native species especially at Sheep Creek N which was isolated from its burned pair. The increase at the unharvested/unburned Miller control may have occurred because of its close proximity to harvested and burned treatment units which could have been the source of non-native seeds.

The four burned treatment units had a common non-native plant species response in that they all showed initial increases followed by a decline in post-fire years. Both burned Miller site areas were resilient to the increases in non-native plant species, decreasing to pre-fire levels. Non-native plant species at Wolf Pasture and Redstreak levelled off at amounts that were greater than pre-fire, possibly indicating a longer-term change of state.

Overall, the results do not clearly point to burning as the sole cause for short-term increases of non-native species. The results also do not mimic the responses of exposed mineral soil indicating that level of exposed mineral soil is not a good indicator of infestation by non-native species. An additional important factor for invasion by non-native species is, no doubt, the proximity of propagules of these species.

Table 4. Short-term response of non-native plant species presence/absence to prescribed fire**.** Years tested always included the year before the prescribed fire, the year of prescribed fire, and one or two post-fire years.

	Treatment		Fire Weather Codes & Indices			BEC unit	Response Period (yr)	Response Curve
Treatment unit	**Harvest**	**Burn**	**DMC**	**DC**	**FWI**			
Sheep Creek N	yes	no burn	NA	NA	NA	IDFdm2	4	
Wolf Pasture	yes	2004	44	399	22	PPdh2	4	
Redstreak HB	yes	2005/09	40/10	360/223	21/4.5	IDFdk5	3	
Redstreak H NB	yes	no burn	NA	NA	NA	IDFdk5	3	
Miller - Harvest Burn	yes	1998	46/27	238/240	20/0	PPdh2	4	
Miller - Harvest	yes	no burn	NA	NA	NA	PPdh2	4	
Miller - Burn	no harvest	1998	46/27	238/240	20/0	PPdh2	4	
Miller - Control	no harvest	no burn	NA	NA	NA	PPdh2	4	

3.1.2 Long-term effects

Five treatment units were sampled at longer term periods following prescribed fire. Four Miller Road treatment units were re-sampled after 14 years and the burned treatment unit at Redstreak was sampled 4 and 12 years after burning.

Exposed mineral soil as a risk indicator

Miller Road

By year 14 following prescribed fire, no treatment units had more exposed soil than that found pre-fire. In fact, soil exposure was less on the Control and Burn treatments (Fig. 2). The Harvest Burn and Harvest treatment units had higher levels of exposed mineral soil than the Control at year 14.

It should be noted that the Harvest treatment unit was subjected to a prescribed fire outside of the original site design at year 10 (Appendix A-1) and this may have resulted in a short-term increase in exposed soil that was missed by the sampling regime. The later prescribed fire was conducted under fire weather conditions conducive to a more severe fire than was the case with the original fire (Table 2).

Exposed soil levels recovered to pre-fire levels at some point after year 2 post-fire on burned treatments. Levels of mineral soil exposure were higher after 14 years on the harvested compared with the unharvested/unburned control area.

Redstreak

At Redstreak long-term data was only available for the burned treatment unit. The unburned treatment unit was sampled until year 4 following the fire. Soil exposure was unchanged ($p>0.05$) on the unburned unit over time. The burned area, subjected to two prescribed fires showed no recovery to pre-burn levels by 7 years after the second prescribed fire (Fig. 3). It was not possible to determine soil exposure resulting from the first prescribed fire due to timing of sampling. Despite this concerning pattern at Redstreak, the level of soil exposure (48% frequency) was comparable to Miller Road pre-fire level of 44%.

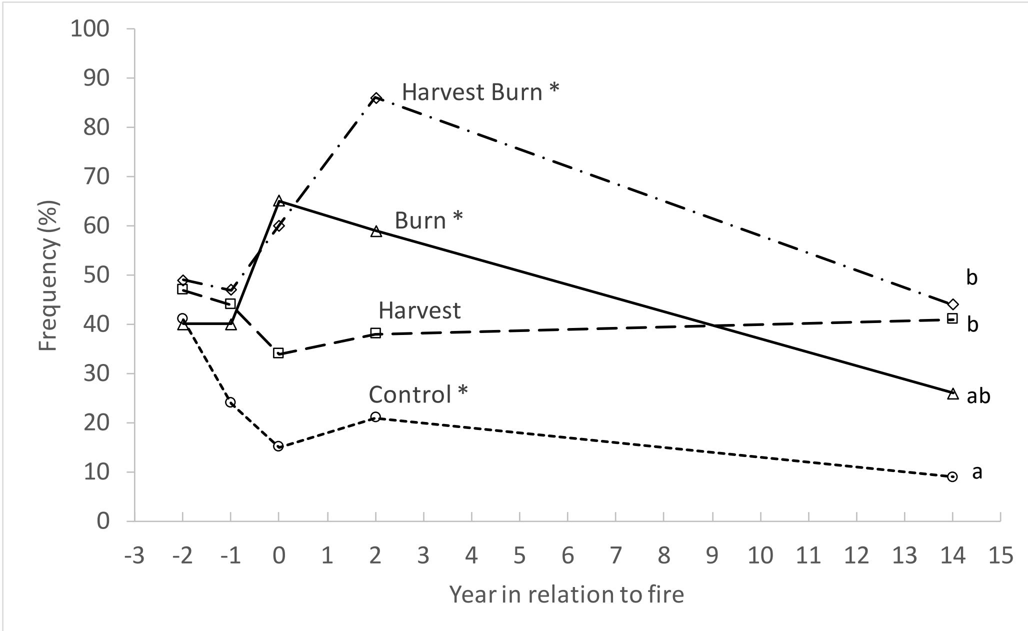


Figure 2. Long-term changes in mineral soil exposure on four treatment units at Miller Creek. Analyses were conducted on presence/absence counts but presented as percent frequency to standardize among sites and for ease of interpretation. Different letters indicate significant differences between treatment units (p<0.05) at year 14. Asterisks indicate significant differences (p<0.05) among years within treatment units.

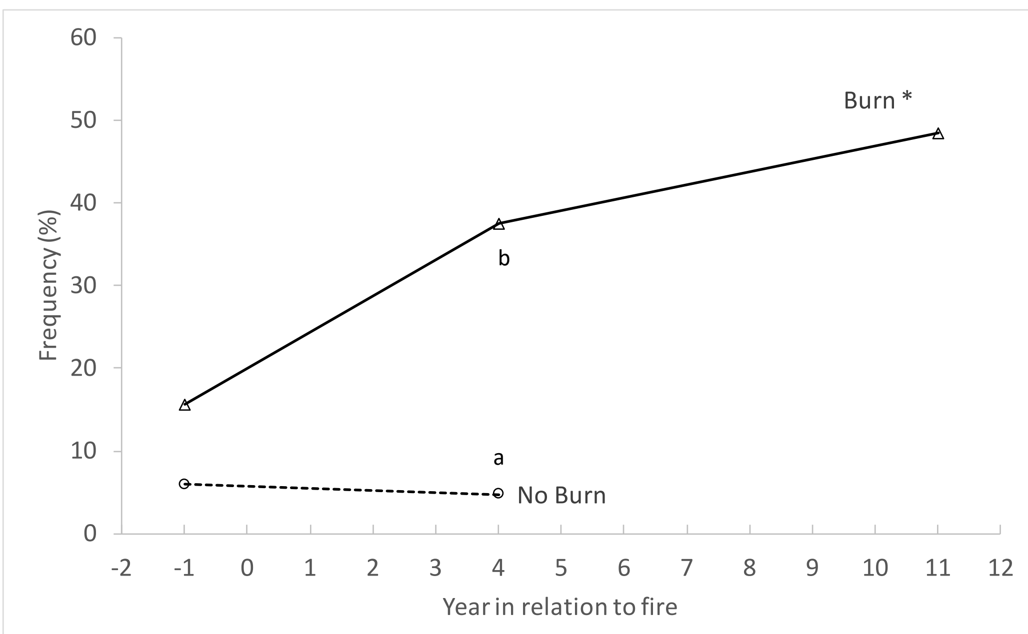


Figure 3. Long-term changes in mineral soil exposure at Redstreak. Analyses were conducted on presence/absence counts but presented as percent frequency to standardize among sites and for ease of

interpretation. Different letters indicate significant differences between treatment units ($p<0.05$) at year 4. Asterisks indicate significant differences ($p<0.05$) among years within treatment units.

Changes in the levels of non-native plant species

The various treatments applied at the Miller Road site did not result in long-term differences of non-native species abundance (Fig. 4). All treatment units displayed a spike in non-native species abundance during the year of fire followed by rapid recovery.

The prescribed burn at Redstreak resulted in an immediate increase of non-native species abundance. This level was maintained in subsequent years, remaining almost the same 11 years after the fire (Fig. 5). The level of non-native species was not different on burned and unburned treatment units at year 4. This suggests that burning was not the cause of the increase of non-native species. Non-native species didn't increase significantly ($p=0.31$) over time on the unburned area, despite a large difference in means (Fig. 5). This non-intuitive statistical result is likely due to high variation of the data. Means and standard errors for unburned treatment unit were: 2004 = 20.2 ±11.0, 2005 = 23.8 ± 10.7, 2009 = 44.0 ± 10.7.

Synthesis

The response over time of individual non-native species was summarized across 5 primary and 16 secondary treatment units. Sampling periods and treatments varied widely. All treatment units were burned at least once (Table 1). Dandelion occurred on all 21 treatments units and continued to increase on almost half of these areas (Table 5). This species is not considered a threat to ecosystem functioning but is an indicator of potential risk of invasion by species with similar reproductive strategies (i.e. windborne perennials with long-distance dispersal). Black medic, another nuisance species, was also common but was declining at most areas. This species relies on persistent seed banks, requiring disturbance to expose dormant seeds to sunlight. It was present in the plant community at many treatment units before treatment. Yellow salsify occurred at over half of the areas and is a species of some concern (Invasive Alien Plant Program). In some areas of BC, it is highly persistent and can become co-dominant with grassland species. It was a recent introduction at most affected sites suggesting a trend that may result in greater abundance and spread. The only other species that occurred in more than 50% of treatment units was Canada bluegrass, an agronomic that has become widely naturalized (Dobb and Burton 2013). This species can spread invasively and is expected to increase with fire because of its rhizomatous nature yet had declined or was declining in most of the affected areas in this study (Table 5).

All other non-native species occurred in less than 25% of the areas, and only two were increasing at most of affected areas. Two FRPA-listed species, Canada thistle and bull thistle, both showed a decreasing trend in most affected areas (Table 5). Sulphur cinquefoil and St. John's wort (FRPA-listed) occurred at only a few sites but had an increasing trend. St. John's wort is under biological control but has recently been suspected to be increasing in BC (S. Turner, pers. comm., Feb. 2018). Sulphur cinquefoil, a FRPA-listed species of considerable concern was continuing to increase at all three areas where it was recorded. Sulphur cinquefoil was first collected in the East Kootenays in the 1940's (Powell 1996) and at present is frequent throughout the Rocky Mountain Trench, especially below Columbia Lake (IAPP 2017). This species requires soil disturbance to germinate. Seeds will not germinate in darkness (Baskin and Baskin 1990) and are persistent in the soil seed bank for at least two years (Kiemnec and McInnis 2009). Most seeds are not dispersed far beyond the parent plant unless transported by animal vectors (Werner and Soule 1976). Therefore, it's increase following prescribed fire will be strongly related to 1) pre-treatment presence in the plant community or soil seed bank and 2) the level of soil exposure resulting from the fire.

Sulphur cinquefoil did not increase over a 15-year period within an exclosure that prevented grazing by cattle and wildlife (Wikeem et al. 2012), maintaining 3% cover between 1994 and 2009. Increases of 4% in 10 years (1999 to 2009) and 11% in 17 years (1999 to 2016) at two grazed sites suggests that grazing is an important factor in its increase (Wikeem et al. 2012).

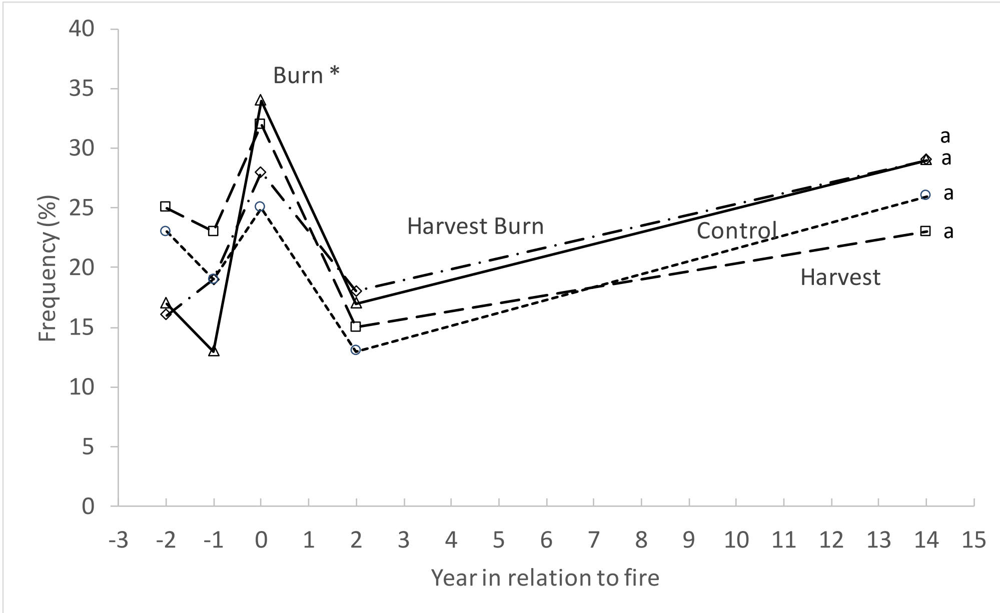


Figure 4. Long-term changes in non-native plant species on four treatment units at Miller Road. Analyses were conducted on presence/absence counts but presented as percent frequency to standardize among sites and for ease of interpretation. Different letters indicate significant differences between treatment units (p<0.05) at year 14. Asterisks indicate significant differences (p<0.05) among years within treatment units.

Figure 5. Long-term changes in non-native plant species at Redstreak. Analyses were conducted on presence/absence counts but presented as percent frequency to standardize among sites and for ease of interpretation. Different letters indicate significant differences between treatment units (p<0.05) at year 4. Asterisks indicate significant differences (p<0.05) among years within treatment units.

Table 5. Summary of responses of non-native plant species over time on 21 burned treatment units.

Non-native species	Category[2]	Trend[1]						Total	Common response
		Incr	Decr/incr	Flat	Decr	Incr/decr	Lost		
common dandelion	nuisance	10		5	1	2	1	21	Incr
black medic	nuisance	5		3		6	1	17	Incr/decr
yellow salsify	tracked	6		2	1	1	1	13	Incr
Canada bluegrass	agronomic	2	1	2		3	3	11	
cheatgrass	tracked	2		1		2		5	
field filago	nuisance	1		1			1	5	
Kentucky bluegrass	agronomic						5	5	Lost
perennial sow-thistle	tracked			1		2		5	Decr
Canada thistle	FRPA listed	1				2	1	4	Incr/decr
quackgrass	agronomic	2					2	4	
red clover	agronomic			2			2	4	
bull thistle	FRPA listed	1				2		3	Incr/decr
common St. John's-wort	FRPA listed	2		1				3	Incr
white sweet-clover	agronomic						3	3	Lost
sulphur cinquefoil	FRPA listed	3						3	Incr
alsike clover	agronomic						3	3	Lost
mullein	tracked			1		1		2	
smooth brome	agronomic			1				1	
littlepod flax	nuisance						1	1	
horseweed	nuisance			1				1	
annual hawksbeard	nuisance			1				1	
red fescue	agronomic						1	1	
European king devil	nuisance	1						1	
summer-cypress	tracked						1	1	
oxeye daisy	FRPA listed			1				1	
alfalfa	nuisance	1						1	
yellow sweet-clover	nuisance						1	1	
common timothy	agronomic						1	1	
tall tumble-mustard	nuisance						1	1	

[1]Incr=increasing at last sample date; Decr/incr=decreased initially then increasing; Flat=no change over time; Decr=decreasing at last sample date; Incr/decr=increased initially then decreasing; Lost=sampled previously but not present at last sampling; Total=number of treatment units where the species was found.

[2]FRPA listed=regulated under the Invasive Plant Regulation/Forest and Range Practices Act (FRPA); nuisance=not considered a problem; agronomic=intentionally seeded or escaped domestic plants with some forage value; tracked=monitored by the Invasive Alien Plant Program (IAPP) (BC Ministry of Forests, Lands and Natural Resource Operations).

3.2 To what extent is restoration burning achieving objectives related to increasing bunchgrass abundance?

3.2.1 Short-term

In our study area there are 11 early-, mid- and late-seral perennial native caespitose grasses classified as bunchgrasses (Appendix A-3). Bunchgrasses did not respond to the burning treatment on three burned treatment units, showing the same lack of response as on three unburned treatment units. The Redstreak site was the exception because bunchgrasses increased on burned and unburned treatment units over the three-year period (Table 6). This suggests that the harvest treatment may have been responsible for the increase in bunchgrass.

Rough fescue, bluebunch wheatgrass and Idaho fescue are late seral bunchgrasses (Wikeem et al. 2012). These grasses responded in much the same way as all bunchgrasses with some differences. There was a decline and slight recovery at Wolf Pasture, which was burned, and a slight decline at the Miller unburned/unharvested control (Table 7). The Redstreak site had increases of late seral bunchgrass on burned and unburned treatment units.

3.2.2 Long-term

Bunchgrass

There was no difference in bunchgrass abundance among the four treatments at Miller Road 14 years after treatments. There was a slight increase in abundance over time on the Harvest treatment unit, but this was likely caused by a rebound from the depression immediately following the non-experimental fire (Fig. 6). There was no difference ($p>0.05$) from pre-fire levels. Bunchgrass declined on the Miller Control treatment unit over time. The bunchgrass abundance on the burning treatment at Redstreak was not different ($p>0.05$) from the unburned treatment at year 4, however it was greater than pre-burn level by year 11 in the burned treatment (Fig. 7).

Late seral bunchgrass

The four treatments at Miller Road did not alter the amount of late seral bunchgrass in the long-term. Late seral bunchgrass was reduced over time on the Burn and Control treatments (Fig. 8). This suggests that some background factor such as grazing or drought caused the decline. Late seral bunchgrass increased over the long-term (11 years) at Redstreak but was not different from the unburned treatment after 4 years (Fig. 9). The long-term increase of bunchgrass at Redstreak was mostly due to increases in the amount of junegrass and late seral rough fescue.

Table 6. Short-term response of bunchgrasses to prescribed fire**.** Years tested always included the year before the prescribed fire, the year of prescribed fire, and one or two post-fire years. All years were consecutive.

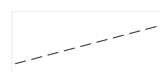
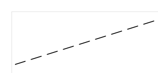
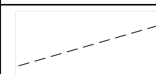
	Treatment		**Fire Weather Codes and Indices**			**BEC unit**	**Response Period (yr)**	**Response Curve**
Treatment unit	**Harvest**	**Burn**	**DMC**	**DC**	**FWI**			
Sheep Creek N	yes	no burn	NA	NA	NA	IDFdm2	4	
Wolf Pasture	yes	2004	44	399	22	PPdh2	4	
Miller - Burn	no harvest	1998	46/27	238/240	20/0	PPdh2	4	
Miller - Harvest Burn	yes	1998	46/27	238/240	20/0	PPdh2	4	
Miller - Harvest	yes	no burn	NA	NA	NA	PPdh2	4	
Miller - Control	no harvest	no burn	NA	NA	NA	PPdh2	4	
Redstreak HB	yes	2005/09	40/10	360/223	(21)/4.5	IDFdk5	3	
Redstreak H	yes	no burn	NA	NA	NA	IDFdk5	3	

Table 7. Short-term response of late seral grasses to prescribed fire**.** Years tested always included the year before the prescribed fire, the year of prescribed fire, and one or two post-fire years. All years were consecutive.

	Treatment		**Fire weather**					
Treatment unit	**Harvest**	**Burn**	**DMC**	**DC**	**FWI**	**BEC unit**	**Period (yr)**	**Response**
Sheep Creek N	yes	no burn	NA	NA	NA	IDFdm2	4	
Wolf Pasture	yes	2004	44	399	22	PPdh2	4	
Miller - Burn	no	1998	46/27	238/240	20/0	PPdh2	4	
Miller - Harvest Burn	yes	1998	46/27	238/240	20/0	PPdh2	4	
Miller - Harvest	yes	no burn	NA	NA	NA	PPdh2	4	
Miller - Control	no	no burn	NA	NA	NA	PPdh2	4	
Redstreak HB	yes	2005/09	40/10	360/223	(21)/4.5	IDFdk5	3	
Redstreak H	yes	no burn	NA	NA	NA	IDFdk5	3	

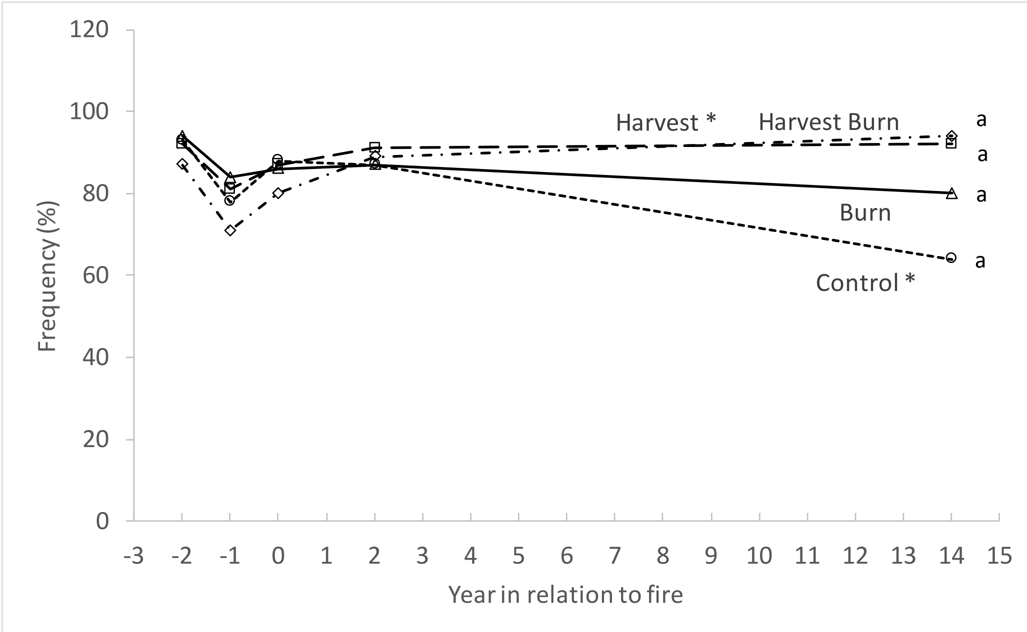


Figure 6. Long-term changes in bunchgrasses on four treatment units at Miller Road. Analyses were conducted on presence/absence counts but presented as percent frequency to standardize among sites and for ease of interpretation. Different letters indicate significant differences between treatment units (p<0.05) at year 14. Asterisks indicate significant differences (p<0.05) among years within treatment units.

Figure 7. Long-term changes in bunchgrasses at Redstreak. Analyses were conducted on presence/absence counts but presented as percent frequency to standardize among sites and for ease of interpretation. Different letters indicate significant differences between treatment units (p<0.05) at year 4. Asterisks indicate significant differences among years (p<0.05) within treatment units.

Figure 8. Long-term changes in late seral bunchgrasses on four treatment units at Miller Road. Analyses were conducted on presence/absence counts but presented as percent frequency to standardize among sites and for ease of interpretation. Different letters indicate significant differences between treatment units ($p<0.05$) at year 14. Asterisks indicate significant differences ($p<0.05$) among years within treatment units.

Figure 9. Long-term changes in late seral bunchgrasses at Redstreak. Analyses were conducted on presence/absence counts but presented as percent frequency to standardize among sites and for ease of interpretation. Different letters indicate significant differences between treatment units ($p<0.05$) at year 4. Asterisks indicate significant differences ($p<0.05$) among years within treatment units.

3.3 What effect does burning have on the re-establishment of tree seedlings?

Presence/absence counts of tree regeneration were available from all primary sites except Redstreak. Miller Road provided short- and long-term data for Douglas-fir and ponderosa pine (4 treatment units), while Sheep Creek North (1 treatment unit) and Wolf Pasture (1 treatment unit) provided short-term data for Douglas-fir.

Short-term

Prescribed fire immediately reduced ($p<0.05$) Douglas-fir regeneration at all 3 burned treatment units analysed (Fig. 10) (Wolf Pasture not shown). Decreases ranged from 68% to 88%. There was no significant reduction on the 3 unburned treatment units monitored over the same time period (Sheep Creek North not shown).

Ponderosa pine regeneration was reduced ($p<0.10$) by 55% and 84% on the 2 burned treatment units analysed at Miller Road (Fig. 11). There was no significant reduction on the 2 unburned treatment units at Miller Road.

Long-term

There were no statistically significant differences in Douglas-fir or ponderosa pine regeneration among the Miller Road treatment units after 14 years (Figs. 10 & 11). However, tends over time within treatment units were significant and provide useful information. Douglas-fir regeneration on the Miller Road Burn treatment unit was reduced by 75% immediately after fire was applied and the reduced level was mostly sustained for 14 years. A similar reduction occurred at the Miller Road Harvest Burn treatment unit, with an immediate 68% reduction which recovered slightly to 55% of pre-fire levels (Fig. 10).

Ponderosa pine regeneration on the Miller Road Burn treatment unit decreased ($p<0.10$) by the second post-fire year to 77% of pre-fire level, maintaining the drop until year 14. The Harvest Burn treatment unit showed the same initial decrease, however there was substantial recovery of ponderosa pine by year 14. An initial 85% decrease recovered to 31% of pre-fire levels.

Counts of cattle manure pats and deer and elk pellets indicate that the Miller Road site was used by these species over time, but these measurements are not sensitive enough to determine actual levels of grazing and browsing.

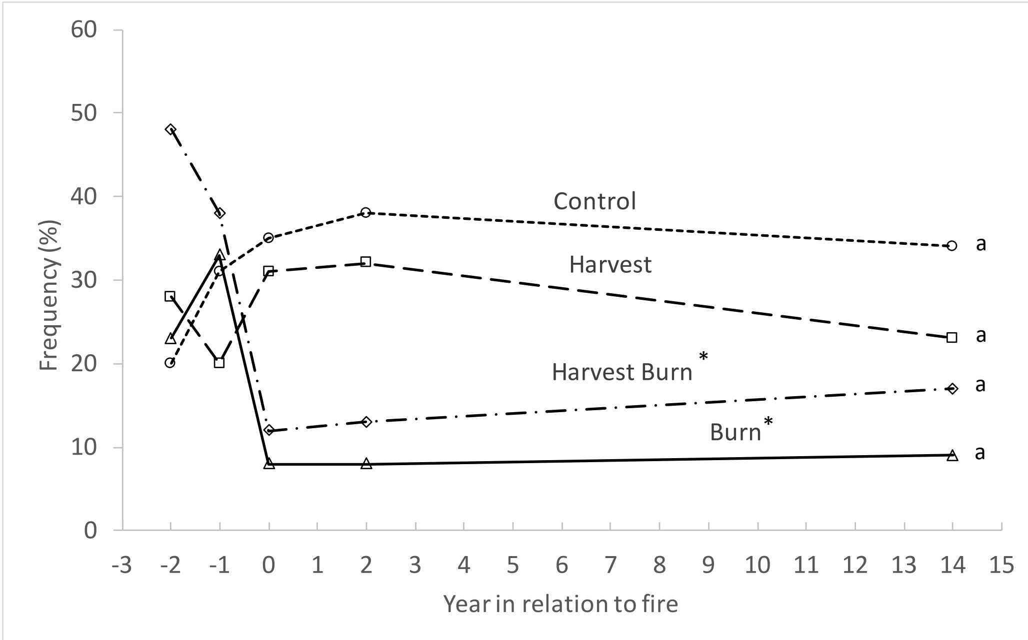


Figure 10. Long-term changes in Douglas-fir regeneration on four treatment units at Miller Road. Analyses were conducted on presence/absence counts but presented as percent frequency to standardize among sites and for ease of interpretation. Different letters indicate significant differences between treatment units ($p<0.05$) at year 14. Asterisks indicate significant differences ($p<0.05$) among years within treatment units.

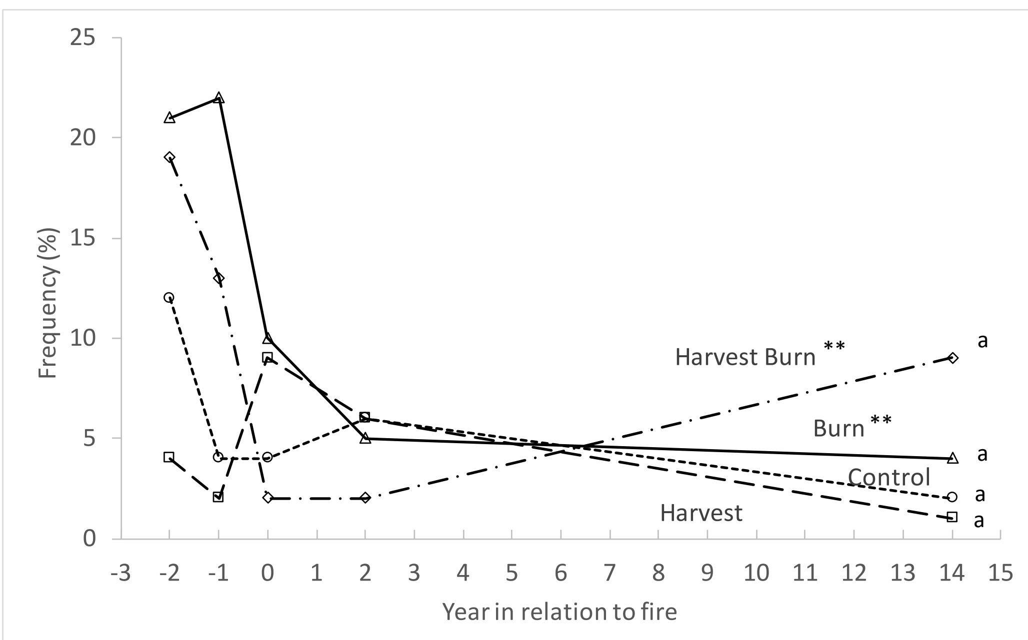


Figure 11. Long-term changes in ponderosa pine regeneration on four treatment units at Miller Road. Analyses were conducted on presence/absence counts but presented as percent frequency to standardize among sites and for ease of interpretation. Different letters indicate significant differences between treatment units ($p<0.05$) at year 14. Double asterisks indicate significant differences ($p<0.10$) among years within treatment units.

3.4 Is there a difference in plant species composition response on IDF versus PP sites?

3.4.1 Synthesis

The response over time of individual bunchgrass species was summarized across all burned primary (5) and secondary (16) treatment units. The treatment units were broken into two groups to examine differential responses by BEC zone.

IDF Zone

Bluebunch wheatgrass was the most prevalent bunchgrass in the IDF, occurring at all eight areas (Table 8). Spreading needlegrass and rough fescue were the next most prevalent bunchgrasses in this zone. The most common response to burning for these three grasses was an increase, although there was a wide mix of other responses including decreasing, maintaining, and being lost (extirpated). All other bunchgrasses were decreasing, including late-seral Idaho fescue.

PP Zone

Rough fescue was the most prevalent bunchgrass in the PP zone and occurred in all 13 treatment units. Spreading needlegrass, junegrass and bluebunch wheatgrass were also prevalent in almost all treatment units. The response of bunchgrass in the PP zone was quite different from the IDF. All three bunchgrasses considered to be late-seral were decreasing or lost completely in the PP zone (Table 8). Mid-seral spreading needlegrass and Columbia needlegrass showed increasing trends. These results suggest that burning was much more successful in achieving increases in late-seral bunchgrass in the IDF zone.

Establishment of bunchgrass from seed is infrequent in the Rocky Mountain Trench. Broadcast seeding of native grasses had low success in the Invermere Forest District (Page 2002). The PP occurs on the driest sections of the southern Rocky Mountain Trench (Braumandl and Curran 1992) therefore new plant establishment bunchgrass seed would be even less likely. Combining both BEC zones, spreading needlegrass was the most common bunchgrass found to increase after burning, doing so on 9 of the 17 treatment units where it was found.

Table 8. Response of common bunchgrass species over time from 21 burned treatment units separated by BEC zone.

Bunchgrass species	BEC zone	Response over time following burning						Total	Common response
		Incr	Decr/incr	Flat	Decr	Incr/decr	Lost		
bluebunch wheatgrass	IDF	4		1	1	1	1	8	Incr
spreading needlegrass	IDF	3		2			1	6	Incr
rough fescue	IDF	3	1	1			1	6	Incr
junegrass	IDF	1		1	1	2		5	Decr
Idaho fescue	IDF				1	2	1	4	Decr
Columbia needlegrass	IDF				1	1	1	3	Decr
needle-and-thread grass	IDF	1					1	2	Decr
stiff needlegrass	IDF				1			1	Decr
IDF Total	IDF	12	1	5	5	6	6	35	
rough fescue	PP	3		4	5		1	13	Decr
spreading needlegrass	PP	6	1	2		1	1	11	Incr
junegrass	PP	3		3	4		1	11	Decr
bluebunch wheatgrass	PP	1		1	3	1	5	11	Lost
Idaho fescue	PP			3	2		3	8	Flat/Lost
Columbia needlegrass	PP	4			1		1	6	Incr
stiff needlegrass	PP			3		1		4	Flat
needle-and-thread grass	PP				1		1	2	Decr/Lost
PP Total	PP	17	1	16	16	3	13	66	

[1]Incr=increasing at last sample date; Decr/incr=decreased initially then increasing; Flat=no change over time; Decr=decreasing at last sample date; Incr/decr=increased initially then decreasing; Lost=sampled previously but not present at last sampling; Total=number of treatment units where the species was found.

3.4.2 Ordination

Plant species composition response to fire and environmental variables was examined using the harvested then burned treatment units from each of the primary sites (total of 3 treatment units). Pre-fire and post-fire plant species presence/absence counts were used as well as physical measures such as presence/absence of soil, rocks and coarse fuel. Only short-term responses are presented because ordination of long-term data did not reveal a strong ordering of plant species along a fire-effects gradient. This weak long-term ordering of plant species to fire may indicate that plant communities are resilient to the effects of fire in the long-term. Other factors such as initial species composition, degree of opening due to harvest treatment, and post-fire management may be more important than fire. Short-term ordination was conducted using data from the year before the fire and the year of the fire (2 years total).

Miller Road Harvest Burn (PPdh2)

Short-term NMDS ordination of the Miller Road Harvest Burn treatment unit did not show a clear response to fire. A graphical display of macroplot positions along the two primary ordination axes did not separate pre-fire macroplots from post-fire macroplots. This indicates that fire was not a major cause of variation among macroplot species composition. It may be the case that fire was not evenly applied over the entire treatment unit or that pre-existing vegetation was very heterogenous among macroplots.

Wolf Pasture (PPdh2)

The NMDS ordination of plant species presence/absence counts showed a clear separation of pre-fire and post-fire plots along axis 1, although a stress level of 0.21 indicates a weak and somewhat suspect relationship (Fig. 12). Axis 1 therefore is an indication of fire effect on plant species/substrate abundance. Axis 2 of the ordination separated north aspect macroplots from south aspect macroplots somewhat clearly but only after fire was applied. This suggests that fire had different effects on south-facing (hotter and drier) than north-facing plant communities. This hypothesis is consistent with the expectation that fuel conditions would be drier on south facing aspects and lead to a more severe burn. It may also be the case that plant communities on south facing aspects have inherent qualities that result in different outcomes following fire. Inspection of the original pre-fire plot data using indicator species revealed that south facing plots were characterized by having equal amounts of rough fescue and bluebunch wheatgrass with little spreading needlegrass, while north facing plots were characterized by equal amounts of spreading needlegrass and rough fescue with no bluebunch wheatgrass. The difference in bluebunch wheatgrass is expected due because of its preference for hotter/drier sites but is not enough to explain different fire effects. Drier fuels on the south facing site at the time of fire is a more likely explanation for different effects.

The bi-plot vectors[2] on the ordination provided a graphical summary of the important plant species and substrates that resulted in the selection and orientation of the two axes. Some of the plant species/substrates on the extreme opposite ends of Axis 1 are consistent with the known effects of fire. Younger Douglas-fir regeneration and antelope bitterbrush are both commonly reported to be reduced following fire so their positions on the graph make sense. The position of rock and soil on the opposite end of the axis also makes sense because a smouldering fire will consume surface organic layers to the point of exposing rock and soil.

[2] A bi-plot is a graph of the species ordination results and macroplot position ordination results. A vector represents the direction of a species response as determined by the ordination.

The plotted positions of spikelike goldenrod and timber milk-vetch on the fire-affected side of Axis 1 is less expected. A possible explanation is that south facing plots suffer greater loss of surface organic layers leading to the exposure of mineral soil seed bed, which was then vulnerable to colonization by windblown seeds, such as from spikelike goldenrod. Organic layers on north-facing plots are not as impacted yet are susceptible to colonization by known seed banking species such as timber-milkvetch and early blue violet.

Redstreak Burn (IDFdk5)

The Redstreak site was burned in 2005 and 2009. Fire weather conditions during the first burn were conducive to a more severe fire than during the second burn but less severe than conditions during the Wolf Pasture burn (Table 4). This site was originally broken into two blocks. Block 1 was relatively level and had more fuel on the ground while block 2 had variable topography and is slightly drier due to a southwest aspect (Page 2004). Major bunchgrass species were not greatly different. Block 2 was more resistant to infestation by non-native species following burning.

The NMDS ordination of plant species counts showed a clear separation of pre-fire and post-fire plots from both axes, tending to locate the post-fire plots into one quadrant (Fig. 13). The stress level of 0.19 was weak and therefore the ordination is somewhat suspect. Axis 1 represents a gradient of fire effect on plant species/substrate abundance. Pre-fire macroplots moved to the positive side of Axis 1 after fire was applied. Axis 2 may be a moisture or temperature gradient, but this is not clear. Axis 2 separated block 1 macroplots from block 2 macroplots more discretely after fire was applied. This could indicate a differential effect of fire by moisture/temperature gradient, similar to that seen at Wolf.

The bi-plot vectors and locations of species/substrates were substantially different from Wolf Pasture. Soil and rock were not strong drivers of the ordination. Baldhip rose anchored the pre-fire end of Axis 1 while three non-native species and sedge anchored the fire end. Axis 2 was affected strongly by quackgrass and northern bedstraw. The positions of Block 1 macroplots in the ordination following fire suggest that fire acted uniformly to alter species composition of these plots, making them more alike. Block 2 plots were all influenced by fire, but the effect was less uniform.

Overall

Fire was the major agent of plant species composition change on all plots at Wolf Pasture and Redstreak, but not at Miller Harvest Burn. There were few similarities between the ordination at Wolf Pasture and Redstreak. This may be due to their different zones but there is not enough information to substantiate this. Variables that represent large novel increases were major factors in the ordination (e.g., exposure of soil and rock and increases in non-native species). Increases in early colonizers from windborne and seed bank species was a common characteristic at both sites. The influence of aspect in differentiating plot response to fire was clear at Wolf Pasture and was possibly also important at Redstreak. Increases in exposed soil was a major factor at Wolf Pasture only.

Figure 12. Non-metric dimensional scaling ordination of Wolf Pasture macroplots based on count of 17 plant species and 3 substrate types for pre-fire (2004) and post-fire (2005) years. Stress = 0.21.

Code	Common name		Code	Common name
ACHNRIC	spreading needlegrass		PENSCON	yellow penstemon
AMELALN	saskatoon		POA_COM	Canada bluegrass
ANTEMIC	white pussytoes		PSEUMEN	Douglas-fir regen
ARCTUVA	kinnikinnick		PSEUSPI	bluebunch wheatgrass
ASTRMIS	timber milk-vetch		PURSTRI	antelope-brush
CALARUB	pinegrass		ROCK	exposed rock
FESTCAM	rough fescue		SOIL	exposed soil
FRAGVIR	wild strawberry		SOLISIM	spikelike goldenrod
KOELMAC	junegrass		VIOLADU	early blue violet
LITHRUD	lemonweed		WOOD_D	coarse woody debris

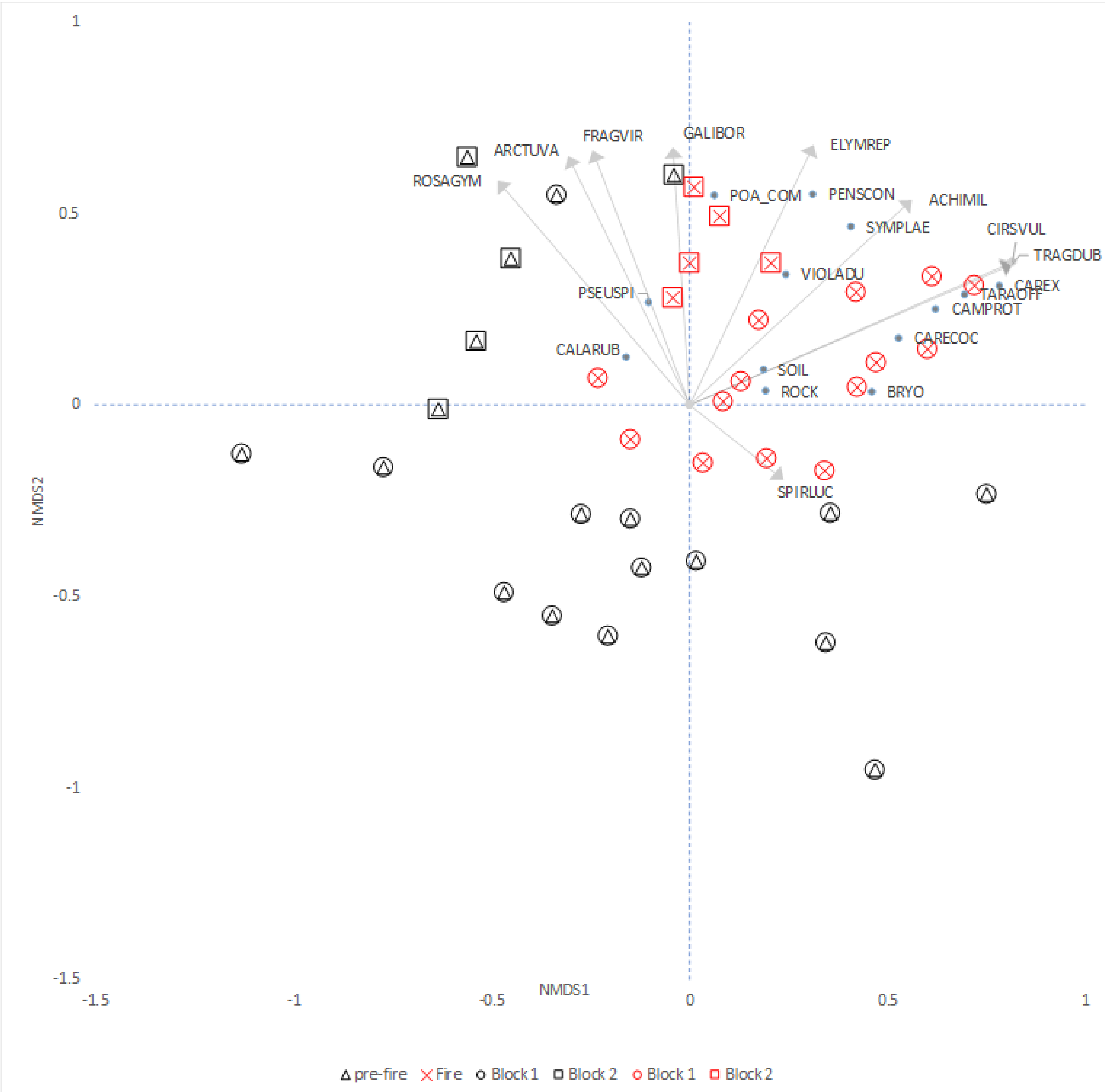


Figure 13. Non-metric dimensional scaling ordination of Redstreak burned macroplots based on count of 19 plant species and 3 substrate types for pre-fire (2004) and post-fire (2009) years. Stress=0.19.

Code	Common name		Code	Common name
ACHIMIL	yarrow		PENSCON	yellow penstemon
ARCTUVA	kinnikinnick		POA_COM	Canada bluegrass
BRYO	moss		PSEUSPI	bluebunch wheatgrass
CALARUB	pinegrass		ROCK	exposed rock
CAMPROT	common harebell		ROSAGYM	baldhip rose
CARECOC	northwestern sedge		SOIL	exposed soil
CAREX	sedge		SPIRLUC	birch-leaved spiraea
CIRSVUL	bull thistle		SYMPLAE	smooth aster
ELYMREP	quackgrass		TARAOFF	common dandelion
FRAGVIR	wild strawberry		TRAGDUB	yellow salsify
GALIBOR	northern bedstraw		VIOLADU	early blue violet

3.5 Fuel reduction

Few datasets included quantification of fuel reduction following prescribed fire. Reduction of larger logs is expected to be strongly dependent on the drought code during the fire. The two observations available support this, with fuel in the 7.5 cm / 7.1 cm or greater diameter classes reduced by 0.09% (DC=223) at Redstreak and 32% (DC=399) at Wolf Pasture (LLYK Fire and Vegetation Management Section 2009, Newman et al. 2012).

4.0 DISCUSSION

4.1 What effect does burning have on mineral soil exposure and establishment and abundance of non-native species?

Our analyses suggest that prescribed fire results in a short-term increase of exposed mineral soil while unburned sites will have no increase over the same period. Longer-term data showed that soil on burned areas recovered to pre-fire levels or better, but that more than two years was required for this to occur. A second prescribed fire may delay the recovery beyond seven years. Level of soil exposure depends on degree of consumption of the duff (FH layers) which is related to the severity of the fire (Hope et al. 2015). Exposed soil creates conditions suitable for the establishment of plant seedlings, either from previously buried seed or seed transported from off-site sources. Exposed soil is therefore necessary for new plant establishment of desirable species, but also increases the risk of infestation by non-native species (Fig. 14). Native and non-native plants are known to spread using similar mechanisms (Bartuszevige and Kennedy 2009). The mix of plant species that eventually colonize the soil openings will depend on the composition of the seed rain and soil seed banks as well as on other plant, site and environment attributes such as germination rate and moisture conditions following germination. Short-term increases of exposed soil, even for one or two years, are important for setting longer-term species trajectories. Plant species introductions will occur at a much slower rate after the soil gaps are closed.

Figure 14. Young bluebunch wheatgrass plants (green stems) sharing a soil crack with cheatgrass (red stem), near Kamloops.

All eight treatment units examined had short-term increases of non-native plant species, including unburned control sites. Many of these responses could be characterized as spikes, with non-native species returning to pre-fire levels within a brief period. A decline in non-native species cover on restored sites in the Rocky Mountain Trench was also reported by Page (2014). Studies from other jurisdictions also generally report low levels of non-native plants (Willms et al. 2017, Bartuszevige and Kennedy 2009). Other responses suggested the potential for longer-term increases, but this only occurred at the Redstreak burn area where non-native species have not decreased following two prescribed fires. There is evidence that non-native species were also elevated to similar levels at the medium-term on unburned areas of this site. This suggests that other factors such as harvesting may have led to the increases.

Overall, the results do not clearly point to burning as the sole cause for short-term increases of non-native species. The results also do not track the levels of exposed mineral soil indicating that level of exposed mineral soil is not a good indicator of infestation by non-native species. Exposed soil may only indicate the potential for invasion. Availability of non-native propagules is an obvious additional essential factor. Where soil disturbance occurs, there will be an increased chance of infestation by seed banking species such as black medic, sulphur cinquefoil and St. John’s wort if these species were on site before the treatment. Similarly, species with windborne seeds such as cheatgrass, perennial sow thistle and bull thistle will be some of the first plants to invade soil gaps if there are abundant seed sources near the site. A summary of 21 treatment units revealed that nuisance weeds, such as dandelion and black medic, were by far the most common. Of the prevalent species, only yellow salsify is a concern, especially given its relatively recent occurrence. Sulphur cinquefoil and St. John’s wort (FRPA-listed) occurred at only a few sites but warrant special concern due to their increasing trend and known potential to spread. Nonetheless, these exotic invasives occur throughout the southern Rocky Mountain Trench and it is not clear whether burning alone is resulting in infestation beyond background levels. Grazing by cattle and wild ungulates may also play a role.

4.2 To what extent is restoration burning achieving objectives related to increasing bunchgrass abundance?

Our quantitative analyses on four burned treatment units (three in the PP zone and one in the IDF) suggested that prescribed fire rarely led to increased bunchgrass, including late seral bunchgrass. Page (2014) and Ross (2013) also reported limited bunchgrass response following ecosystem restoration in the Rocky Mountain Trench. The one exception was at

Redstreak (IDF zone), which also had atypical long-term increases in soil and non-native species. The success at Redstreak may be related to the continued mineral soil exposure over time which created a longer-term seedbed for bunchgrass establishment compared to other sites. Part of the increase in bunchgrass at Redstreak may have been due to factors other than burning since the same increase occurred on unburned areas.

4.3 What effect does burning have on the re-establishment of tree seedlings?

Dependent on the coverage of the fire, low lying evergreen plants are highly susceptible to even the least severe fire. Where significant amounts of Douglas-fir and ponderosa pine regeneration occurred pre-fire, decreases because of the fire ranged from 68% to 88% immediately post-fire. These losses were mostly sustained for 14 years on the 2 burned treatment units with long-term data.

4.4 Is there a difference in plant species composition response on IDF versus PP sites?

Bunchgrass responses to burning were also summarized over a larger number of treatment units, including eight in the PP zone and 13 in the IDF zone. Bluebunch wheatgrass and rough fescue had increasing trends on 9% and 23% of the PP zone treatment units where they were found, while this rose to 50% for both species on IDF zone sites. This is consistent with the quantitative analysis of primary treatment units which only showed increases at the one IDF site. Overall, there is a suggestion that burning for the objective of increasing bunchgrass has been more successful in the IDF zone. The reverse was reported by Page (2014) who examined the overall effect of ecosystem restoration using earlier data from fewer sites. Another plausible reason for the different results is our use of presence/absence which assigns the same importance to young plants as older plants, possibly picking up incipient trends better.

Although the trends may be promising at some sites, the percent cover of late-seral bunchgrass is far short of the reference condition. The maximum final percent cover of bluebunch wheatgrass and rough fescue at 18 burned treatment units was only 6% and 5.5% with averages of 1.0% and 0.7%. Bluebunch wheatgrass and rough fescue have the potential to reach 55% and 59% cover in completely open conditions in the Rocky Mountain Trench PP zone (Wikeem et al. 2012). A restored area in the PP near Kamloops achieved greater than 50% cover of rough fescue (Fig. 15). In IDF zones near Kamloops and Merritt rough fescue often reaches greater than 80% cover in late-seral grassland plant communities (Krzic et al. 2014).

Successful recovery of bunchgrass cover following restoration burning likely requires more time, especially when the density of bunchgrass remnants is very low to start with. Rapid increases in bunchgrass can occur when residual plant density is high before restoration treatments (Fig. 15). At low bunchgrass density, it may require 20 years for bluebunch wheatgrass and 30 years for rough fescue to become dominant at an open site (Wikeem et al. 2012); possibly longer when grazed. Grazing by cattle and elk is likely interfering with rates of natural plant succession (Fig. 16). Cattle will increase grazing use of burned areas (Fuhlendorf and Engle 2004; Vermeire et al. 2004; Angell et al. 1986; Hilmon and Whitaker 1964) as will elk (Hobbs and Spowart 1984; Rowland et al. 1983; Canon et al. 1987; Van Dyke and Darragh 2006). This comes from increased palatability of lush (litter free) grass regrowth and from an increase in crude protein of the forage. The combination of these two factors may increase the time for full bunchgrass recovery beyond 30 years.

Figure 15. Rapid rough fescue recovery two years after harvesting/thinning restoration treatment at Monte Creek hydro line site.

Figure 16. Un-grazed and grazed rough fescue site near Merritt, BC. Rough fescue is highly palatable, preferred by livestock and wild ungulates, with little resistance to continuous grazing (Mack and Thompson 1982).

4.5 Conclusions

Soil exposure is a normal consequence of prescribed fire, even under moderate fire weather conditions prescribed for ecosystem restoration. Soil exposure on ecosystem restoration sites is both beneficial and harmful. Population increases of desirable plants require the same mineral soil seedbeds that non-native invasive plants exploit. The best way to deal with this predicament is not to avoid all possibility of exposed soil, because this will limit initial increases of desirable species. Avoiding treatment of sites with high occurrence of exotic invasive species may be the better option.

Objectives regarding promotion of grassland plant communities have not yet been achieved, even on sites monitored for 14 – 17 years post-fire. It is suspected that even under ideal conditions it will require 20 or more years for late seral bunchgrass species to become dominant. Grazing by livestock and wild ungulates may be interfering with plant succession.

Despite the abundant data from monitoring efforts over the past 20 years in the Rocky Mountain Trench, it was challenging to produce meaningful analysis which included multiple sites due to inconsistency in treatments, monitoring schedules and sampling design. For the purposes of producing better information, we recommend focusing resources on three or four well sampled sites, using standard treatment combinations including a control, and standard monitoring schedules and sampling designs. This is similar to recommendations provided by Page (2014). As recommended by Ross (2013) providing wildlife/cattle exclosures will increase the value of these sites.

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Appendix A-1. *Fire weather details for the burned primary treatment units.*

Station name	Johnson Lake	Johnson Lake	Johnson Lake	Johnson Lake	Radium	Radium	Radium
Treatment units	Miller B, Miller HB	Miller B, Miller HB	Miller H	Wolf Pasture	Redstreak	Redstreak	Redstreak
Year	1998	1998	2008	2004	2005	2005	2009
Month	4	4	4	4	4	4	4
Day	3	11	27	22	21	22	8
Max. temperature (^{0}C)	15.1	6.7	14.9	17.5	21.4	22.7	18.5
Relative humidity (%)	38	70	27	27	30	14	24.4
Wind speed (km/hr)	13.5	8	10.6	9.6	1.5	5.1	4.8
Wind direction (degrees)	180	225	185	180	0	225	186
Precipitation (mm)	0.3	5.7	0	0	0	0	0
FFMC	89.1	47.7	90.8	90.8	87	91	86
DMC	46.2	26.7	49.4	44.1	40	40	10.2
DC	238.2	239.7	402.0	399.1	360	360	223.2
ISI	7.4	0.2	8.2	7.8			3
BUI	62.2	41.7	75.6	69.2			18.3
FWI	20.1	0.3	23.9	22.0			4.5
Danger forest	3	1	3	3			0.4

Appendix A-2. *Sampling layout details within macroplots for primary and secondary sites.*

Site	Treatment	Transects (subplots)	Transect length (m)	Subplot area (m^2)	Source
Gina Lake	Burned 2010	3(4)	11.28	0.1	Machmer et al. 2002
Gina Lake	Unburned	3(4)	11.28	0.1	Machmer et al. 2002
Redstreak	Burned 05/09	3(4)	11.28	0.1	Page 2009
Redstreak	Unburned	3(4)	11.28	0.1	Page 2009
Rocks	Burned 2006	3(4)	11.28	0.1	Page 2011
Rocks	Unburned	3(4)	11.28	0.1	Page 2011
Miller Road HB	Burned 1998	1(10)	50	0.1	Ross 2013
Miller Road B	Burned 1998	1(10)	50	0.1	Ross 2013
Miller Road H	Burned 2008	1(10)	50	0.1	Ross 2013
Miller Road C	Unburned	1(10)	50	0.1	Ross 2013
Wolf Pasture	Burned 2004	2(10), 2(5)	10	0.1	Newman et al. 2012
Sheep Creek N	Unburned	2(10), 2(5)	10	0.1	Newman et al. 2012
Fontaine N Blk B	Burned 2000	1(29), 1(48), 1(50), 1(52)	NA	5	Page 2011
Fontaine N Blk C	Burned 2000	1(29), 1(48), 1(50), 1(52)	NA	5	Page 2011
Burk	Burned 2004	1(15)	30	0.1	Berg 2016
Rushmere	Burned 2000	1(15)	30	0.1	Berg 2016
Johnson Lake	Burned 1999	1(15)	30	0.1	Berg 2016
Springbrook	Burned 99/05	1(15)	30	0.1	Berg 2016
Premier Sheep	Burned 1999	1(15)	30	0.1	Berg 2016

__Appendix A-3__. List of vascular plant species found at the primary study sites (M=Miller Road; S=Sheep Creek North; W=Wolf Pasture; R=Redstreak).

Common name	Scientific name	Sites	Notes
alfalfa	Medicago sativa	M, R	exotic - agronomic
alpine hedysarum	Hedysarum alpinum	R	native
alsike clover	Trifolium hybridum	M, W, R	exotic - agronomic
American vetch	Vicia americana	M, W, R	native
annual hawksbeard	Crepis tectorum	R	exotic - invasive
antelope-brush	Purshia tridentata	M, S, W	native
arrowleaf balsamroot	Balsamorhiza sagittata	M, S, W,R	native
aster	Aster sp.	S, W, R	native
baldhip rose	Rosa gymnocarpa	S, W, R	native
bastard toad-flax	Comandra umbellata	M	native
birds-foot trefoil	Lotus corniculatus	W	exotic - agronomic
black medic	Medicago lupulina	M,S,W,R	exotic - invasive
black twinberry	Lonicera involucrata	R	native
blue wildrye	Elymus glaucus	M,R	native
blueberry, huckleberry	Vaccinium sp.	M	native
bluebunch wheatgrass	Pseudoroegneria spicata	M,S,W,R	native, late-seral bunchgrass
bluegrass	Poa sp.	M,S	native
bluejoint reedgrass	Calamagrostis canadensis	M,R	native
broad-leaved stonecrop	Sedum spathulifolium	R	native
brown-eyed Susan	Gaillardia aristata	M,W,R	native
bull thistle	Cirsium vulgare	M,S,W,R	exotic - invasive
Canada bluegrass	Poa compressa	M,S,W,R	exotic - agronomic
Canada goldenrod	Solidago canadensis	R	native
Canada thistle	Cirsium arvense	M,S,W,R	exotic - invasive
Canada violet	Viola canadensis	S,W,R	native
catchfly	Silene sp.	S,R	native
cheatgrass	Bromus tectorum	M	exotic - invasive
choke cherry	Prunus virginiana	M	native
cinquefoil	Potentilla sp.	W	native
clover	Trifolium sp.	W	native
Columbia bower	Clematis occidentalis	R	native
Columbia needlegrass	Achnatherum nelsonii	M	native, bunchgrass
common chickweed	Stellaria media	M	exotic - invasive
Canada thistle	Cirsium arvense	M,S,W,R	exotic - invasive
Canada violet	Viola canadensis	S,W,R	native
catchfly	Silene sp.	S,R	native
cheatgrass	Bromus tectorum	M	exotic - invasive
choke cherry	Prunus virginiana	M	native
cinquefoil	Potentilla sp.	W	native
clover	Trifolium sp.	W	native
Columbia bower	Clematis occidentalis	R	native

***Table A-3**. (Continued).*

Common name	Scientific name	Sites	Notes
Columbia needlegrass	Achnatherum nelsonii	M	native, bunchgrass
common chickweed	Stellaria media	M	exotic - invasive
common dandelion	Taraxacum officinale	M,S,W,R	exotic - invasive
common harebell	Campanula rotundifolia	M,S,W,R	native
common hound's-tongue	Cynoglossum officinale	M	exotic - invasive
common juniper	Juniperus communis	M,S,R	native
common plantain	Plantago major	R	native
common silverweed	Potentilla anserina	M	native
common snowberry	Symphoricarpos albus	M,R	native
common St. John's-wort	Hypericum perforatum	M	exotic - invasive
common timothy	Phleum pratense	M,S,R	exotic - agronomic
creamy peavine	Lathyrus ochroleucus	M,W,R	native
creeping Oregon-grape	Mahonia repens	M	native
crested wheatgrass	Agropyron cristatum	M	exotic - agronomic
Cusick's bluegrass	Poa cusickii	R	native
cut-leaved anemone	Anemone multifida	M,S,W,R	native
cut-leaved daisy	Erigeron compositus	M	native
death camas	Zigadenus sp.	W	native
Douglas' knotweed	Polygonum douglasii	S	native
Douglas maple	Acer glabrum	M,R	native
Douglas-fir	Pseudotsuga menziesii	M,S,W	native
dwarf birch	Betula glandulosa	M	native
early blue violet	Viola adunca	M,S,W,R	native
false Solomon's-seal	Maianthemum racemosum	M	native
fescue	Festuca sp.	S,R	native
field chickweed	Cerastium arvense	M,S	native
field filago	Logfia arvensis	S,W,R	exotic - invasive
field locoweed	Oxytropis campestris	M,R	native
field milk-vetch	Astragalus agrestis	W	native
field pepper-grass	Lepidium campestre	M	exotic - invasive
field pussytoes	Antennaria neglecta	S,W,R	native
field sedge	Carex praegracilis	W,R	native
fireweed	Chamerion angustifolium	M,W,R	native
fleabane	Erigeron sp.	M	native
foxtail barley	Hordeum jubatum	M	native
glaucous-leaved honeysuckle	Lonicera dioica	R	native
golden-aster	Heterotheca villosa	M,S,W	native
goldenrod	Solidago sp.	R	native
graceful cinquefoil	Potentilla gracilis	M	native
great mullein	Verbascum thapsus	M,R	exotic - invasive
green alder	Alnus viridis	M	native
green wintergreen	Pyrola chlorantha	M	native
hawkweed	Hieracium sp.	M,W,R	native

Table A-3. (Continued).

Common name	Scientific name	Sites	Notes
heart-leaved arnica	Arnica cordifolia	M,S,R	native
heart-leaved bittercress	Cardamine cordifolia	R	native
hillside milk-vetch	Astragalus collinus	W	native
Holboell's rockcress	Arabis holboellii	S,W,R	native
Hood's phlox	Phlox hoodii	S	native
horseweed	Conyza canadensis	R	exotic - invasive
Idaho fescue	Festuca idahoensis	M,S,R	native, late seral bunchgrass
Indian ricegrass	Achnatherum hymenoides	M	native
junegrass	Koeleria macrantha	M,S,W,R	native, bunchgrass
Kentucky bluegrass	Poa pratensis	M,S,W,R	exotic - invasive
kidney-leaved violet	Viola renifolia	M,R	native
kinnikinnick	Arctostaphylos uva-ursi	M,S,W,R	native
lamb's-quarters	Chenopodium album	R	exotic - invasive
large-leaved avens	Geum macrophyllum	R	native
leafy aster	Symphyotrichum foliaceum	M,S,W,R	native
lemonweed	Lithospermum ruderale	M,S,W,R	native
littlepod flax	Camelina microcarpa	W	exotic - invasive
locoweed	Oxytropis sp.	M,R	native
lodgepole pine	Pinus contorta	M,W	native
long-leaved fleabane	Erigeron corymbosus	M	native
low northern sedge	Carex concinna	S	native
low pussytoes	Antennaria dimorpha	M	native
mariposa lily	Calochortus sp.	S,W	native
meadow death-camas	Toxicoscordion venenosum	M,R	native
Menzies' campion	Silene menziesii	R	native
mock-orange	Philadelphus lewisii	M	native
mountain alder	Alnus incana	M	native
mountain death-camas	Zigadenus elegans	S	native
mountain sweet-cicely	Osmorhiza berteroi	M	native
mustard	Brassicaceae	M	native
narrow-leaved collomia	Collomia linearis	W	native
narrow-leaved goosefoot	Chenopodium leptophyllum	M	native
narrow-leaved hawkweed	Hieracium umbellatum	S,W	native
needle-and-thread grass	Hesperostipa comata	M,W,R	native, bunchgrass
needlegrass	Stipa sp.	S,W	native, bunchgrass
night-flowering catchfly	Silene noctiflora	S	exotic - invasive
nine-leaved desert-parsley	Lomatium triternatum	M,S,W	native
nodding onion	Allium cernuum	M,S,W,R	native
nodding trisetum	Trisetum cernuum	M	native
nodding wood-reed	Cinna latifolia	M	native
Nootka rose	Rosa nutkana	R	native
northern bedstraw	Galium boreale	M,R	native
northern fairy-candelabra	Androsace septentrionalis	M	native

***Table A-3**. (Continued).*

Common name	Scientific name	Sites	Notes
northern gentian	Gentianella amarella	S,W,R	native
northwestern sedge	Carex concinnoides	M,S,W,R	native
Norwegian cinquefoil	Potentilla norvegica	M	native
Nuttall's pussytoes	Antennaria parvifolia	M,S,W	native
oatgrass	Danthonia species	R	native
oceanspray	Holodiscus discolor	M	native
old man's whiskers	Geum triflorum	M,W	native
orange arnica	Arnica fulgens	M,R	native
orchard-grass	Dactylis glomerata	M	exotic - agronomic
oxeye daisy	Leucanthemum vulgare	R	exotic - invasive
paintbrush	Castilleja sp.	M	native
pearly everlasting	Anaphalis margaritacea	M	native
penstemon	Penstemon sp.	M,S,W	native
perennial sow-thistle	Sonchus arvensis	M,S,R	exotic - invasive
pinegrass	Calamagrostis rubescens	M,S,W,R	native
pink twink	Phlox gracilis	W	native
ponderosa pine	Pinus ponderosa	M,S,W	native
prairie crocus	Anemone patens	M	native
prairie rose	Rosa woodsii	M,S,W	native
prickly rose	Rosa acicularis	M,S,W,R	native
purple peavine	Lathyrus nevadensis	M,W	native
purple-leaved willowherb	Epilobium ciliatum	S,W,R	native
pussytoes	Antennaria sp.	W	native
pyramid spirea	Spiraea x pyramidata	M	native
quackgrass	Elymus repens	S,W,R	exotic - agronomic
racemose pussytoes	Antennaria racemosa	S,W,R	native
red clover	Trifolium pratense	M,R	exotic - agronomic
red fescue	Festuca rubra	R	exotic - agronomic
red raspberry	Rubus idaeus	M,R	native
redtop	Agrostis gigantea	M	exotic - agronomic
rockcress	Boechera sp.	M	native
Rocky Mountain butterweed	Packera streptanthifolia	S,W	native
Rocky Mountain fescue	Festuca saximontana	R	native
Rocky Mountain juniper	Juniperus scopulorum	M,S	native
rose	Rosa sp.	M	native
rough fescue	Festuca campestris	M,S,W,R	Native, late-seral bunchgrass
rough-leaved ricegrass	Oryzopsis asperifolia	M,R	native
round-leaved alumroot	Heuchera cylindrica	M,W,R	native
rush	Juncus sp.	M	native
sagebrush mariposa lily	Calochortus macrocarpus	M,S	native
sand dropseed	Sporobolus cryptandrus	M	native
Sandberg's bluegrass	Poa secunda	M	native

Table A-3. *(Continued).*

Common name	Scientific name	Sites	Origin
saskatoon	Amelanchier alnifolia	M,S,W,R	native
scarlet paintbrush	Castilleja miniata	M	native
Scouler's hawkweed	Hieracium scouleri	M,S,W,R	native
sedge	Carex sp.	M,S,W,R	native
shaggy fleabane	Erigeron pumilus	M,W	native
shining starwort	Stellaria nitens	S,W,R	native
shiny-leaved meadowsweet	Spiraea lucida	M,S,R	native
short-awned ricegrass	Piptatheropsis pungens	R	native
short-beaked agoseris	Agoseris glauca	M,S,W,R	native
showy aster	Eurybia conspicua	M,S,R	native
showy daisy	Erigeron speciosus	M	native
silky locoweed	Oxytropis sericea	W	native
silky lupine	Lupinus sericeus	M	native
silky phacelia	Phacelia sericea	M	native
slender hawksbeard	Crepis atribarba	M,S,W,R	native
slender hawkweed	Hieracium gracile	M	native
slender wheatgrass	Elymus trachycaulus	M,S,W,R	native, bunchgrass
small-flowered blue-eyed	Collinsia parviflora	S,W,R	native
small-flowered nemophila	Nemophila parviflora	M	native
small-flowered penstemon	Penstemon procerus	M,R	native
smooth aster	Symphyotrichum laeve	S,W,R	native
smooth brome	Bromus inermis	M,R	exotic - agronomic
snowberry	Symphoricarpos sp.	R	native
snowbrush	Ceanothus velutinus	M	native
soopolallie	Shepherdia canadensis	M,S,W,R	native
spikelike goldenrod	Solidago simplex	M,S,W,R	native
spreading dogbane	Apocynum androsaemifolium	M,S,R	native
spreading needlegrass	Achnatherum richardsonii	M,S,W,R	native, bunchgrass
spreading phlox	Phlox diffusa	S,W	native
squaw currant	Ribes cereum	M	native
starwort	Stellaria sp.	M	native
stiff needlegrass	Achnatherum occidentale	M,S,W,R	native, bunchgrass
streambank butterweed	Packera pseudaurea	R	native
sulphur cinquefoil	Potentilla recta	M	exotic - invasive
summer-cypress	Kochia scoparia	R	exotic - invasive
sweet-scented bedstraw	Galium triflorum	R	native
tall annual willowherb	Epilobium brachycarpum	W	native
tall Oregon-grape	Mahonia aquifolium	S,R	native
tall tumble-mustard	Sisymbrium altissimum	R	exotic - invasive
thickspike wildrye	Elymus lanceolatus	M	native
thin-leaved owl-clover	Orthocarpus tenuifolius	M	native
Thompson's paintbrush	Castilleja thompsonii	M,S,W	native

Table A-3. *(Continued).*

Common name	Scientific name	Sites	Origin
three-spot mariposa lily	Calochortus apiculatus	M,S	native
timber milk-vetch	Astragalus miser	M,S,W,R	native
timber oatgrass	Danthonia intermedia	M,R	native
trembling aspen	Populus tremuloides	M,R	native
tufted phlox	Phlox caespitosa	M,S,W	native
twinflower	Linnaea borealis	M,R	native
umber pussytoes	Antennaria umbrinella	S,W,R	native
upland larkspur	Delphinium nuttallianum	M	native
Utah honeysuckle	Lonicera utahensis	R	native
viper's bugloss	Echium vulgare	M	exotic - invasive
western larch	Larix occidentalis	M,R	native
western meadowrue	Thalictrum occidentale	M	native
western snowberry	Symphoricarpos occidentalis	W,R	native
western wheatgrass	Pascopyrum smithii	W	native
white hawkweed	Hieracium albiflorum	M,S,W	native
white pussytoes	Antennaria microphylla	M,S,W,R	native
white sweet-clover	Melilotus alba	M,R	exotic - agronomic
whitlowgrass	Draba sp.	W	native
wild bergamot	Monarda fistulosa	M	native
wild sarsaparilla	Aralia nudicaulis	M	native
wild strawberry	Fragaria virginiana	M,S,W,R	native
willow	Salix sp.	M	native
wood bluegrass	Poa nemoralis	M	exotic - invasive
woolly groundsel	Packera cana	M,S,W,R	native
woolly plantain	Plantago patagonica	M	native
yarrow	Achillea millefolium	M,S,R	native
yellow bell	Fritillaria pudica	S	native
yellow hedysarum	Hedysarum sulphurescens	M,S,W,R	native
yellow king devil	Hieracium caespitosum	M	exotic - invasive
yellow owl-clover	Orthocarpus luteus	M	native
yellow penstemon	Penstemon confertus	M,S,W,R	native
yellow rattle	Rhinanthus minor	M	native
yellow salsify	Tragopogon dubius	M,S,W,R	exotic - invasive
yellow sweet-clover	Melilotus officinalis	R	exotic - agronomic