Native and non-native invasive plant response to burn severity two years after the 2005 School Fire in Pomeroy, WA

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Invasive plant species have been spreading rapidly in forests of the western U.S., posing serious ecological and economic threats. The purpose of this study was to determine the effects of fire severity on native and non-native plant response two years after the 2005 School Fire. The results show that high severity burn areas contained more non-native plant species than areas burned with medium and low severity. Non-native plant species occurred in less than 20% of high burn severity plots with a maximum percent canopy cover of 2%. Non-native plant species were absent in unburned plots. Approximately half of the common species in fire-affected areas originated from seed and half were resprouts. Although annuals appeared in all levels of fire severity, perennials were more abundant than annuals, even in high severity burns. The invasive species present in high severity burn areas may increase in future years and continue to persist in other disturbed locations.

Key Terms: *wildfire, fire effects, Umatilla National Forest*

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Executive summary

Plant species invasions following wildfires have become a major concern (Brooks et al. 2004), as global warming will cause more and larger fires (Westerling et al. 2006). Managers were very concerned about non-native plant species invasions following the School Fire, which burned in the Umatilla National Forest in August 2005. Invasive species can pose many ecological and economic threats to native ecosystems (Brooks et al. 2004). The severity of a wildfire can affect plant response, so understanding native and non-native plant response to burn severity could help managers mitigate species invasions after fires.

Severe burns are characterized by canopy removal, exposure of mineral soil, and increased availability of resources. These sites are therefore susceptible to changes in vegetation composition because non-native plants are able to quickly exploit and colonize such areas. Low and moderate severity burns can stimulate the growth of native plants and are thus expected to be less susceptible to invasion.

Invasive species occurred in all fire-affected sites two years after the School Fire that burned ~21,000 ha in 2005, but high severity burn areas contained more non-native species than low or medium severity burns, as was expected. The potential for continued invasion of non-native plants remains high in these areas. Low and medium severity sites showed a strong response of native forbs. Non-native plants are expected to decline in abundance as the native vegetation continues to recover.

Because all fire-affected sites contained non-native plant species, fire is not an effective tool to curtail the spread of these species and managers should exercise caution when planning a prescribed burn. Prescribed burns should be conducted under conditions which would minimize the proportion burned severely. It is also recommended that monitoring be conducted prior to a

possible burn to determine if a threat of weed invasion exists. After wildfires, reseeding with native species may be helpful in preventing large-scale invasions of non-native plants into severely burned areas.

I. Introduction

A. Background

Fire is an important disturbance process in many ecosystems. After almost a century of fire suppression, stands in many dry forest ecosystems have become very dense. Fuel build-up has also reduced productivity in many ecosystems and altered natural fire regimes (Agee 1993). As a result of fuel accumulation and global climate change, the number of large fires has increased (Westerling et al. 2006), leaving landscapes vulnerable to opportunistic invasive plant species. Non-native plant invasions are a major threat to forest ecosystems because they can alter successional pathways, decrease native plant and animal communities, decrease herbivore carrying capacities, and alter fire regimes and fire behavior (Robichaud et al. 2004, Brooks et al. 2004). The US Forest Service has named non-native plant invasions as one of the most serious economic and environmental threats to the United States (Robichaud et al. 2004), while globally, alien species invasions are listed as a critical threat to biodiversity (Wilcove et al. 1998, Brooks et al. 2004).

Following wildfire, managers anticipate increases in invasive weeds and associated weed seed production (Robichaud et al. 2004, Brooks et al. 2004). A disturbance such as fire provides conditions favorable to the invasion of non-native plant species, including reduction in tree canopy cover and density, an increase in exposed mineral soil, and an increase in forest floor light levels (Smith et al. 2008; Robichaud et al. 2004; Crawford et al. 2001). Fire can stimulate soil microbial processes, seed germination, seed production and sprouting, all of which result in changes in the structure and composition of soils and vegetation (Lentile et al. 2006). The effect of burn severity on non-native plant invasions has received little scientific attention, but as the threat of fire will likely increase in the future, research in this area is critical. Improved scientific understanding would help in assessing the effects of the interactions of fire, climate change and invasive species in the western United States.

Many western forests that burned in recent years have been invaded by aggressive weed species that inhibit or displace native forest plants (Robichaud et al. 2004). Native plant communities play important structural and functional roles in the landscape (Krebs 1994). Invasive plants can compete with native species for resources and cause changes in disturbance patterns, nutrient cycling, and fire and hydrological regimes (Smith et al. 2008). All of these factors cause deviations away from native species' environments, inhibiting their ability to thrive. Non-native species can hybridize with native species, reducing genetic fitness, altering the gene pool, and ultimately, reducing biodiversity (Lentile et al. 2008). A decrease in native species would likely result in significant alterations of the inherent structure and function of natural forest ecosystems.

Invasive species may also increase fuel flammability and alter historical fire regimes (D'Antonio and Vitousek 1992, Brooks et al. 2004). For example, in the Selway-Bitterroot Wilderness in Idaho and Montana, spotted knapweed (*Centaurea maculosa*) frequently becomes the dominant species following a fire event (Robichaud et al. 2004). Noxious weeds are also spreading rapidly on rangelands and in dry forests. Cheatgrass *(Bromus tectorum)* has altered the fire regime of much sagebrush steppe, effectively creating a landscape dominated by annual species (Smith et al. 2008).

Both native and invasive species may respond differently to varying degrees of burn severity. The term burn severity is often misused and is difficult to quantify, as it is interpreted in a variety of ways (Lentile et al. 2006). Understanding what is meant by the term *burn severity* is critical for clarifying the changes undergone by landscapes due to fire. Burn severity can be defined as "the degree to which an ecosystem has changed owing to the fire" (Lentile et al. 2006). When satellite or aerial measurements are employed to assess burn severity, differences in vegetation cover are used to characterize burn severity. The level of burn severity increases with the magnitude of vegetation mortality and proportion of charred soil due to extensive soil heating. The Normalized Burn Ratio is frequently used to interpret fire severity from remotely sensed satellite data. When this index is based on differences in broad spectral changes in images before and after fires, it is referred to as the difference in the Normalized Burn Ratio (dNBR) (Lentile et al. 2006). For example, a site with 90% crown scorch and 85% bare, scorched soil would be designated as high severity. These areas are highly susceptible to non-native plant invasions and may not return to their original condition for a long time (Lentile et al. 2006). The relationship between burn severity and invasive species has unfortunately not received much scientific attention. My research aims to further this understanding.

The research presented here will focus on invasive species and native species' response to burn severity and will attempt to characterize likely traits of non-native species found in burned areas. Non-native plants are usually annuals or biennials with a low shade tolerance, short generations, and the ability to produce many seeds (Smith et al. 2008). They also have the ability to rapidly exploit the abundant resources following a fire (Harrod and Reichard 2001). As burn severity increases, resident vegetation and canopy cover decrease, while the amount of bare mineral soil increases, providing potential invaders with abundant resources and light. Severe burn areas are characterized by fewer resprouting species and fewer surviving trees to provide seeds; thus, invasions by wind-blown seed may be more likely (Lentile et al. 2006). In the eastern Cascades, bull thistle (*Cirsium vulgare*) became established after fire due to its small, wind-blown seeds and light requirement for germination (Harrod and Reichard 2001; Smith et al. 2008). Invasive as well as native species may resprout vegetatively from underground root systems, even if the above-ground portion of the plant is burned (Smith et al. 2008). An example of an invasive species capable of resprouting and abundant seed production is Canada thistle (*Cirsium arvense*). In addition, its seeds can remain viable for 20 years and fire can stimulate the germination of its seeds in the seedbank (Harrod and Reichard 2001). Low and moderate severity fires may stimulate resprouting, but high severity fires cause intense soil heating, which may kill above and below-ground plant components (Lentile et al. 2006). For example, ponderosa pine forests in northern Arizona contained more non-natives plant species in areas with more bare mineral soil, while sites with more litter contained an abundance of native species (Smith et al. 2008). Thus, moderate and low severity burn sites may be characterized by more surviving or resprouting native vegetation and are less susceptible to invasions because resources (nutrients, light, and space) are limited. As fires are predicted to become more severe, non-native invasion may pose an even larger problem to western forests and the ability to understand this relationship becomes more important.

B. Hypotheses

Invasive and native plant responses may vary according to burn severity. I hypothesize that:

1. Invasive plants are more abundant in high severity burn areas than in low and moderate severity burn areas. Native species will be more abundant in low and moderate severity burn areas.
2. Severely burned areas will have more annuals and more plants established from seeds than moderate or low severity burned areas.

C. Objectives

The goal of this project is to determine if invasive plant species are more likely to become established after high severity fires and if those species employ specific colonization strategies. In particular, I will:
1. Determine whether presence and percent canopy cover of invasive and native herbaceous species differ in low, medium, and high severity burn areas.
2. Contrast regeneration methods (vegetative reproduction vs. reproduction from seeds) and life span (annual vs. perennial) characteristics of native and invasive plant species responding to a fire. I will also investigate how characteristics differ among low, medium, and high severity burns.

II. Materials and methods

A. Study Area

The School Fire study area is located in southeastern Washington, 16 km south of Pomeroy (Fig. 1)The School Fire started on August 5, 2005 and burned 49,515 acres in grassland and mixed forest habitats. Many fire fighting resources were required to control and eventually extinguish the fire, including 49 engines, 3 helicopters, 4 crews, and 310 people from BLM, DNR, USFS, NPS, FWS, and private entities.

The School Fire burned in a mountainous area with high plateaus and steep, rocky canyons. The fire spread rapidly due to extremely dry fuels, high temperatures and strong winds in harsh terrain. The fire pushed up drainages on multiple fronts and long-range spotting occurred up to 1 km from the main fire. Fifty-six percent of the burned area was under federal management. Of that, 83% was classed as ponderosa pine or mixed-conifer forest before the fire. Of this forested area, 37% had been harvested or partially cut before the School Fire. An additional 10% of the burned area had received fuels treatments in the form of mechanical thinning and/or prescribed fire. To quantify burn severity in the School Fire plots, the dNBR was interpreted from Landsat satellite images taken before and after the fire (Robichaud et al. 2004).

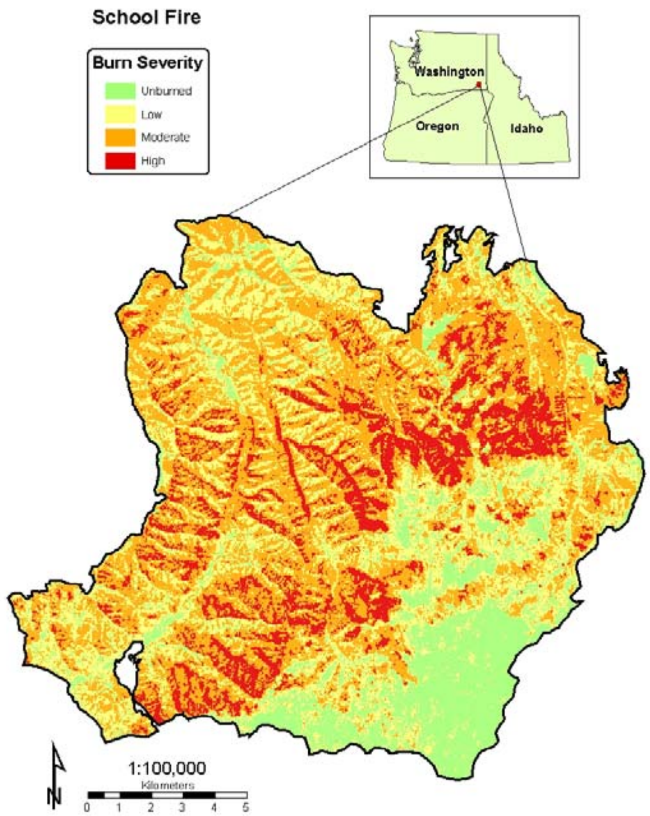

Figure 1.Burn severity of the School Fire in southeastern Washington as interpreted from satellite imagery pre and post-fire using dNBR. Unburned, green (15%); Low, Yellow (28%), Moderate, Orange (43%), and High, Red (14%) (Robichaud et al. 2004).

B. Sampling Design

In 2005, research crews established sample sites following the fire (Robichaud et al. 2004). Sites were distributed according to the severity of the burn and treatment. Burn severity was classified in four categories: control (unburned), low, moderate, and high burn severity. The dNBR provided the basis for burn severity classification. Burn severity assessment was based on: 1) soil characteristics (char depth, organic matter loss, altered infiltration, and color) 2) above ground vegetation consumption; and 3) tree mortality and canopy scorch (Lentile et al. 2007). Sites were located randomly, at least 50 m from a road and perpendicular to slope direction. In the summer of 2007, field crews established additional sample sites to achieve a total sample size of 65 sites to maintain a more balanced sampling design. In order to concentrate on the effect of burn severity on plant response, I analyzed data from the 42 sites sampled in 2007 that had not been seeded or salvaged after the fire.

C. Plot Description

Field plots measured 60x60 m and were laid out perpendicular to the site contour (Figure 2). A circular 8-m radius plot was placed in the center of the plot where trees and tree characteristics were measured. Crews recorded the size and condition of snags and trees (>12.7 cm diameter). A 1-m^2 subplot was located at the center of the circular tree plot. Four more 1-m^2 subplots were located at the terminus of the 30-meter site radii. At each of the sub plots crews took the following observations: 1) species-level vegetation cover and composition, 2) percent cover of ash, mineral soil, and litter present, and 3) litter and duff depth.

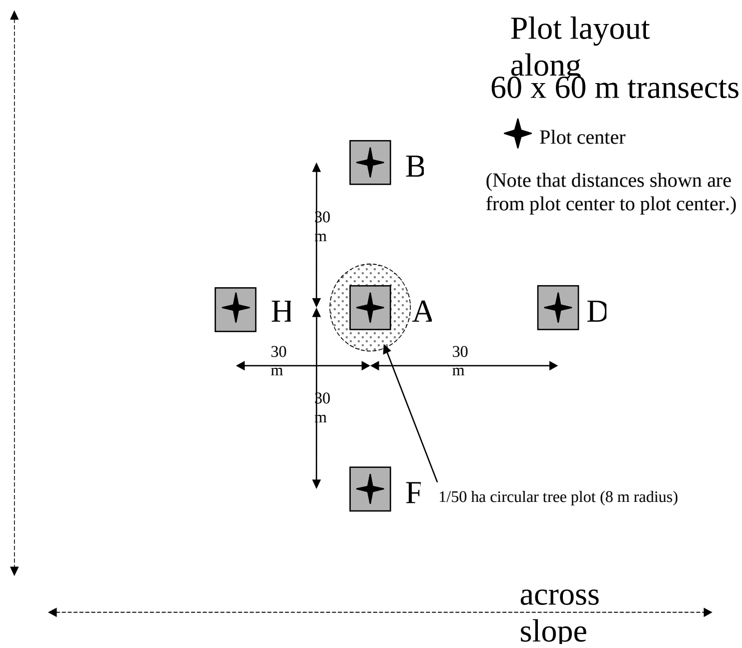

Figure 2. Sample plot lay-out of School Fire, southeastern Washington (Robichaud et al. 2004)

D. Data analysis

I reporting here on the data collected in 2007. Simple descriptive data analyses using SAS version 9.1 statistical package (SAS Institute 2008) were used to identify data entry errors. Subsequently, the species were classified according to physiognomic layer (i.e., grasses, forbs, shrubs, and tree seedlings). To provide a general description of the site conditions of each of the treatments, percent cover was calculated for each physiognomic layer for each plot and for each treatment. I then tested for differences in plant abundance among treatments using the non-parametric Kruskal-Wallis test. This nonparametric one-way Analysis of Variance was employed, rather than the parametric equivalent, because the data were skewed and not normally distributed. Similar analyses were conducted for ground layers (i.e., bare ground, litter and moss) and for overall tree cover to further assess burn severity for each of the treatments.

Frequency analysis was used to determine the composition and relative abundance of the species encountered, according to physiognomic layer and treatment, based both on their cover and presence. I calculated constancy based on the number of plots a species was present on divided by the total number of plots sampled per treatment (plot constancy) and for the number of sites a species was present (site constancy). Based on mean percent cover per species, the most common species were selected for weeds (n=3), grasses (n=4), forbs (n=7), and shrubs (n=3). For each of these species I tested differences in percent cover among treatments using the Kruskal-Wallis test, because the data were not normally distributed. Pairwise comparison tests were used to determine specifically which treatments differed from one another. An exact nonparametric statistical technique for pairwise comparisons does not exist, but an approximate procedure, based on Bonferroni inequalities for large sample sizes, was used (Gibbons 1993).

III. Results and Discussion

Native and non-native plant responses to burn severity were evaluated by percent cover and by frequency analysis (constancy). Changes in percent cover were examined by physiognomic layer and for selected species with the highest percent cover. Changes in percent cover are indicative of the magnitude or strength of the response. Changes in constancy (by physiognomic layer and for the eight most common species) are an indication of the consistency of the response.

A. The effect of burn severity with respect to species coverage

A.1. Site characteristics

As expected, percent canopy cover of trees decreased with increasing burn severity (Fig. 3, Table 1). Mean percent canopy cover of trees was significantly lower in high burn severity sites (17%) as compared to the control (31%) and low (31%) burn severity sites but not to medium severity sites (Fig. 3, Table 1 and Table 2). There was significantly more bare ground present in high burn severity sites (18%) than in either medium or low severity sites (2% and 2%, respectively) but not as compared to the control sites (33%; Fig. 3, Table 1 and 2). Sites subjected to fire seemed to have less litter than control sites, but none of the differences were significant (P= 0.10), perhaps because of high variability in post-fire conditions. More moss was present in burned sites than in the control, but only the difference between high burn severity and control sites (18% vs. 11%; Table 1) was significant.

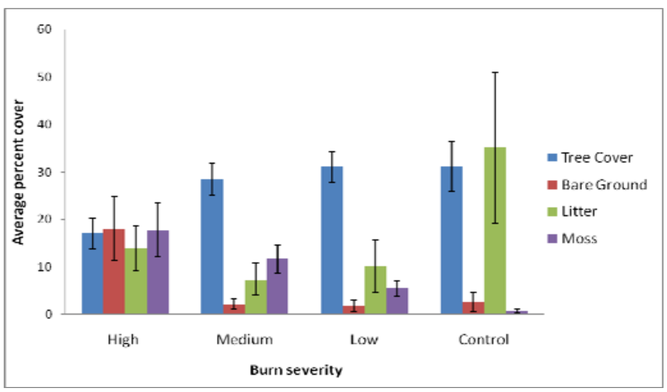

Fig 3. Percent cover of trees, bare ground, litter, and moss by burn severity. Data collected during the 2007 School Fire field season. Error bars indicate standard error.

Thus, two years after the 2005 School Fire, the effects are most pronounced in high severity sites. Tree canopy cover was reduced by almost half, the amount of bare ground increased substantially, and the amount of litter decreased relative to unburned controls. High burn severity is also associated with a marked increase in moss cover. Many studies have shown that fire moss, *Ceratodon purpureus*, which was the main species found on School Fire sites as well, to be especially abundant in high severity burn sites (Tesky 1992). Medium and low severity burn sites generally do not differ from the control sites in tree canopy, litter, and moss cover, which may be due to a certain degree of recovery since the fire. The site characteristics indicate that the potential for non-native invasion exists, especially in high severity burn sites (Lentile et al. 2004; Smith et al. 2008; Robichaud et al. 2004).

A.2. Overall vegetation response

Vegetation response to the 2005 School Fire by physiognomic layer (grasses, forbs, shrubs and tree seedlings) in 2007 is shown in Fig. 4 and Table 3. Percent cover of grasses tended to be higher in high and medium severity sites as compared to low severity and control sites, but the differences are not statistically significant. Forb cover was significantly reduced in high severity sites (16% as compared to 25% for the control sites; Table 3). Forb cover increased slightly, although not significantly, in low and moderate severity sites. In high severity sites, shrubs tend to have a slightly higher percent cover than in the control or the low and medium severity sites. Tree seedlings have a significant, progressively lower percent cover in response to increasingly higher burn severity as compared to the control sites (1%, 1%, and 11% vs. 5% for the control sites; Table 3).

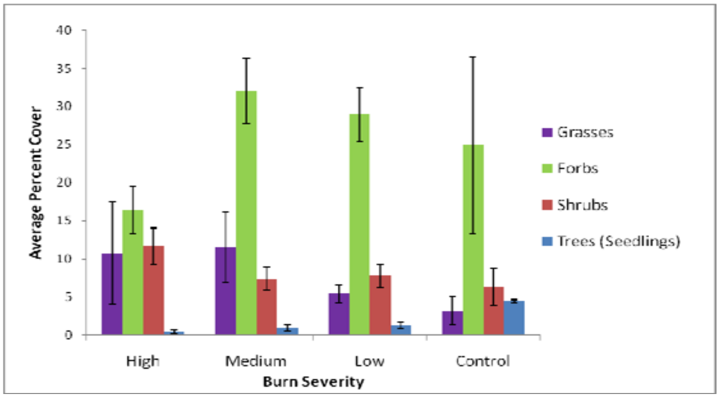

Fig 4. Percent cover of grasses, forbs, shrubs, and trees (seedlings) by burn severity. Data collected during the 2007 School Fire field season. Error bars indicate standard error.

Fire seems to have a stimulating effect on forbs and to a lesser extent on shrubs and grasses, but on sites burned with high severity forb cover was reduced by about 40% relative to the unburned control plots. Tree seedlings did not respond positively to any burn severity. These results are similar to those found by Lentile et al. (2007) immediately and one year post-burn for eight wildfires across the western US.

A.3. Native vegetation response by species

A.3.1 Graminoids

The trends for graminoids are similar to those found when common species are examined individually (Table 4). Grasses tend to increase somewhat with increasing burn severity, but none of the differences are statistically significant. The trend is strongest in *Festuca idahoensis*, which increases from less than 10% in low severity burns to 22% cover in high severity sites.

The exception is *Carex geyeri*, which shows reduced percent cover with increasing burn severity; only percent cover in high severity sites is significantly lower than in control sites (0% vs. 2%; Table 4). *Carex geyeri* typically regenerates quickly following fire, but shows much variability in its response to fire (Chadwick 2002).

A.3.2 Forbs

Forbs generally show an increase in percent canopy cover from control to medium burn severity, followed by a reduction in cover in high burn severity sites. This trend is particularly strong (and statistically significant) for *Claytonia perfoliata*, *Lactuca serriola*, *Stellaria spp*. and *Epilobium angustifolium*, which were absent in unburned sites and reach the highest percent cover in sites burned with moderate severity (8%, 2%, 22%, and 3%, respectively; Tables 4 and 2). Only *Epilobium angustifolium* maintains this higher percent cover in high severity sites. All these species produce abundant seeds which are easily spread and apparently exploit the openings created by fire. *Epilobium angustifolium* is a common post-fire species (Lentile et al. 2007) which quickly colonizes areas with low tree canopy cover and then reduces in abundance with an increase in tree canopy cover. Although *Lactuca serriola* is not native to the U.S. and is considered "weedy and invasive' in some parts of the country, states such as Washington do not list it as a noxious weed. It is not considered to be a threat to Washington ecosystems (Washington State Noxious Weed Control Board 2010). *Anemone* spp. is an exception to the general trend; it shows a decrease (not statistically significant) in percent cover with increasing burn severity.

A.3.3 Shrubs

Shrubs had a very low percent cover in unburned control sites. Shrub cover was higher on burned sites and increased with increasing burn severity, in particular for *Salix scouleriana* (0% in control sites vs. 6% in high severity sites; Table 4 and Table 2). This may be due to the colonizing abilities of *Salix scouleriana*. It easily becomes established in open, disturbed areas from windblown seeds (Anderson 2002). Percent cover for *Salix* spp. and *Spiraea betulifolia* show a slight decrease in high severity burn sites. *Spiraea betufolia* is a fire-resistant species and is stimulated to regenerate from rhizomes following a medium or low severity fire event. However, high severity fires often result in mortality of the underground portion of the plant (Habeck 1991), which would explain the observed trend.

A.4. Invasive species response

Weeds were not very common in the study plots two years after the fire. Only three species listed as invasive species by the state of Washington (USDA 2009) were present (Table 4), including two forbs, *Cirsium arvense* and *Cirsium vulgare*, and one grass, *Bromus tectorum*. Even low severity burns seem to create opportunities for these species to become established, which increase with increasing burn severity. However, only percent cover for *C. vulgare* is significantly higher in high severity burn sites as compared to control sites (2% vs. 0%; Tables 4 and 2). *Cirsium vulgare* and *C. arvense* are early successional species (Zouhar 2001; Zouhar 2002), which are usually absent in undisturbed forest, as was found in the present study. The rapid invasion of these species into burned areas has been well documented (Smith et al. 2008; Zouhar 2001). Their seeds are easily spread by wind, humans or animals, and the reduction in tree canopy cover in high severity sites increases light on the forest floor, a condition necessary for seed germination (Zouhar 2002). Whereas *C. vulgare* usually establishes shortly after disturbance and then declines as other vegetation recovers, establishment of *C. arvense* may be delayed for two or more seasons (Zouhar 2001). Percent cover for the latter species may therefore increase in the coming years, especially in high severity burn sites with a relatively high percentage of bare ground and little competing vegetation. The grass, *Bromus tectorum,* is generally uncommon in mature forest stands, as was found here. It usually increases following disturbance such as fire as it is a strong competitor in the post-fire environment, particularly on severely burned sites (Zouhar 2003). Unless seed sources are nearby, establishment may take several years, because seeds are mainly dispersed by animals and humans. Once a few plants become established, prolific seed production can quickly result in this species' long-term abundance. Thus, the low percent canopy cover in fire-affected sites found in the present study may increase markedly in the coming years, especially in high burn severity areas.

A.5. The response of non-native versus native vegetation

Although areas of high burn severity have been reported to be particularly susceptible to non-native plant invasions (Lentile et al. 2006), I did not find a dramatic increase of weed species in these sites two years after the 2005 School Fire. Only three weed species were found present in the study area, *Cirsium vulgare*, *C. arvense* and *Bromus tectorum*, and all have their highest percent cover in high severity burn sites, but the values are very low (2%, 1% and 0%, respectively; Table 4). Even though this represents an increase compared to the unburned, control sites (0% cover), the values are not as large as expected. There is some evidence to suggest that low and medium severity burn sites were also invaded by these species, but to a lesser degree (Table 4). Since percent canopy cover and percent bare ground on low and medium severity burn sites is not significantly different from control sites two years after the fire, plant invasion may have taken place shortly after the fire occurred when conditions were more favorable.

Percent cover for native forbs, shrubs, grasses and tree seedlings combined increases from 39% for the control sites to 43% for low and 52% for medium severity burn sites (Table 3). The strong response of native species to low and medium severity burns may explain the relatively low percent cover of weed species in these sites. Also, weed species may not be able to persist as recovery of the native vegetation proceeds. However, combined cover of native forbs, shrubs, grasses and tree seedlings decreased in high burn severity sites (to 39%) mainly due to a marked decline in the response of forbs (from 32% in medium severity to 16% in high severity sites; Table 3). Therefore invasive plant species, which are already present in greater number in high severity burn sites, may persist for a longer period of time. As mentioned above, it is also likely that *Cirsium arvense* and *Bromus tectorum* will expand their cover in these sites in the future, especially since there is still a considerable amount of bare ground available. My results thus support the hypothesis that invasive plants are more prevalent in high severity burn areas than in low to medium severity burn areas and that the response of the native vegetation is stronger in low to medium severity burn areas. Invasion of recently burned sites is likely to occur from relatively open areas such as recovering high severity burn sites, roads, and areas disturbed by logging machinery and recreational vehicles. However, invasions are not likely to occur from areas similar to the control sites, where *C. vulgare*, *C. arvense* and *B. tectorum* are virtually absent (0%; Table 4).

B. The effect of burn severity on species abundance

B.1. Species diversity

Fifty-one species were found present in the unburned control sites (Table 5). Slightly more species were found on high burn severity sites as compared to control sites, mainly due to an increase in the number of grasses and to a lesser extent in the number of shrubs. The total number of species is highest in low and medium burn severity sites (100 and 87 species, respectively; Table 5). The number of grasses and shrubs are slightly higher in these sites than in high burn severity sites, but a striking increase in the number of forbs is responsible for most of the increase in species diversity in low to medium burn severity sites (65 and 51 species of forbs, respectively; Table 5). Similar results have been reported by others (e.g. Havlina 1995).

B.2. Abundance of invasive species and native vegetation by physiognomic layer

Observed constancy of the eight most common species per physiognomic layer per plot and per site are shown in Table 6. A relatively high plot constancy and low site constancy indicates a species may be locally abundant, but not common over the entire study site. Conversely, a species with a relatively low plot constancy and high site constancy may be widespread throughout the study area, but locally in low abundance. Generally, plot constancy is lower than site constancy. For instance, *Festuca idahoensis* occurs in about 50% of the sites, but only in about 25% of the plots (Table 6). Grasses seem to have relatively high site constancy as compared to their plot constancy, indicating a more widespread presence in smaller numbers. This is confirmed by their low percent cover per plot (1%; Table 6). Most forbs have relatively high plot constancy as well as high site constancy. They not only occur commonly over the study area but also within a site, except for *Stellaria* spp. and *Anemone* spp., which are locally less abundant (percent canopy cover 11% and <10%, respectively; Table 6). Forbs are generally more common than grasses, with *Arnica cordifolia* having the highest overall constancy (plot constancy 46% and site constancy 86%; Table 6). This species also has a relatively high percent cover per plot (55%). The presence of shrubs is similar to that of grasses in that they tend to occur widespread but locally in limited number and they are generally less common than forbs. Of the weeds, *Cirsium vulgare* occurs in about 50% of the sites, but only in about 15% of the plots (Table 6) which are exclusively in burned sites (Table 4).

B.3. Abundance of invasive species and native vegetation influenced by burn severity

Weeds and eight species of grasses and forbs had high plot constancy across burn severity class (Table 7). The most common species in the unburned control sites are *Carex geyeri, Arnica cordifolia*, *Anemone* spp. (*A. parviflora*, *A. piperi*), *Hieracium albiflorum*, *Festuca idahoensis* and *Thalictrum occidentale*, all of which are typical of mid- to late-seral stages (Chadwick 2002; Reed 1993; Reeves 2006; Zouhar 2000). Their presence generally declines post-fire with increasing fire severity, except for *F. idahoensis* which shows a slight increase (Table 7). The ability for vegetative regrowth in addition to reproduction from seed allows these species, at least initially, to persist after fire, even in high severity burn sites (*A. cordifolia*). Two other species with high plot constancy in control sites are *Epilobium angustifolium* and *Achillea millefolium*, which more typically occur in early successional stages and disturbed sites (Pavek 1992; Aleksoff 1999). Both species have the capacity for strong vegetative regrowth and abundant seed production. In addition, seeds of *E. angustifolium* are widely dispersed by wind (Pavek 1999). Seeds of *A. millefolium* are spread by short distance wind dispersal (Aleksoff 1999).

In fire-affected sites, the above mentioned group of late successional species is present in progressively fewer plots with increasing burn severity (Table 7). For instance, *A. cordifolia* occurs in 60% of the control plots, in 57% of low burn severity plots, but in only 33% and 35% of medium and high burn severity plots. *Carex geyeri* and *Thalictrum occidentale* do not occur in any high burn severity plots. *Spirea betulifolia*, a late seral shrub, shows a marked increase in constancy in low burn severity plots, then declines as burn severity increases. *Spirea betulifolia* is a rhizomatous shrub with strong sprouting ability, and generally has a high survival rate following fire (Habeck 1991).

The early seral species, *Epilobium angustifolium,* becomes more common with increasing burn severity, a trend which is also shown by *Lactuca serriola*, *Bromus carinatus,* and *Elymus glaucus*, as well as the early successional shrub *Salix scouleriana*. The latter four species are not present in undisturbed sites and all regenerate predominantly from wind dispersed seed; *Salix scouleriana* additionally resprouts from the root crown (Anderson 2002). *S. scouleriana* has the highest plot constancy of high burn severity sites (58%; Table 7), but it does not become as readily established after low and medium severity fires, as was found by others (Anderson 2002). Its windblown seeds require mineral soil for germination and establishment (Anderson 2002), conditions which are most likely to occur in high severity burn areas.

Achillea millefolium is more common in low and medium burn severity plots than in undisturbed or high severity plots. The same pattern is stronger in *Claytonia perfoliata*, *Stellaria* spp. (S*tellaria calycantha*), and *Epilobium minutum*. For instance, *C. perfoliata* is not present in control sites, but occurs in about 30% of low and medium burn severity plots and in only 5% of high burn severity plots. *Epilobium minutum* does not occur in high severity burn plots. *C. perfoliata* and *E. minutum* both regenerate from seed which may remain dormant in a seedbank (Matthews 1993).

Of the three invasive species present, *Bromus tectorum* and *Cirsium arvense* seem to follow the trend described above for *Epilobium angustifolium*. The plot constancy of *B. tectorum* increases with fire intensity, but it is not present in undisturbed sites. The perennial *C. arvense* is present in 5% of the control plots; its constancy remains low in low to medium burn severity plots, then increases in high severity burn sites. Higher light intensity and temperature favors germination of its wind dispersed seeds, which may explain a greater presence in sites severely affected by fire (Zouhar 2001). It can also sprout vegetatively from its extensive root system (Zouhar 2001). *Cirsium vulgare* is absent from control plots and its constancy is slightly higher in medium burn severity plots than in either low or high severity plots, a trend more like that described for *Achillea millefolium*. *C. vulgare* reproduces from seed, which is dispersed by wind and animals or human activity, and there is some evidence that its seeds can remain dormant in the seedbank (Zouhar 2002).

B.4. Life span and reproductive strategy in relation to fire severity

The eight most common species in undisturbed plots are all perennials and all are capable of vegetative regrowth as well as reproduction from seed (Table 7). The majority of these species are characteristic of late seral or climax stages. Two species, *Achillea millefolium* and *Epilobium angustifolium*, are more typical of disturbed areas.

In low severity burn plots, many of the species of unburned plots persist, probably due to their strong capability for vegetative regrowth. Such species are often referred to as "endurers" (Agee 1993). Two new common species appear, *Claytonia perfiolata* and *Stellaria* spp. (S*tellaria calycantha*), which both reproduce from seed and most likely came up from the seedbank (Matthew 1993). Such species are also called "evaders" (Agee 1993). Thus, low burn severity seems to indicate a slight shift to a more annual life span and reproduction from seed in the common species.

In medium severity plots, four of the common species of undisturbed plots remain. In addition to the two species which already appeared in low severity burn plots, two new annual species which reproduce from seed are added, *Lactuca serriola* and *Epilobium minutum*. *Epilobium minutum* may have originated from the seedbank, since it is also present in undisturbed sites (Table 7). *Lactuca serriola* has wind-dispersed seeds, so its seed source would likely be offsite "invaders" (Agee 1993). Consequently, in medium severity sites there are about as many annuals as there are perennials and four of the eight common species regenerate predominantly from seed. Also, more of these species are characteristic of early to mid seral stages (6 out of 8).

The same four species of undisturbed plots which persisted in low and medium severity plots, *Arnica cordifolia, Festuca idahoensis, Achillea millefolium* and *Epilobium angustifolium*, continue to be common in high burn severity plots. *Lactuca serriola* reaches its highest plot constancy in high burn severity plots (52%; table 7). In addition, three new common species reproducing from seed appear: two annual/perennial grasses (*Elymus glaucus* and *Bromus carinatus*) and the annual/biennual weed *Cirsium vulgare*. All three species are absent in control sites, and their seeds are likely to have been transported to high severity burn sites by wind and animals or human activity (Johnson 1999; Tollefson 2006; Zouhar 2002). Thus, as in medium burn severity sites, four species are capable of vegetative regrowth as well as reproduction from seed and the remaining four regenerate predominantly from seed. Again, 6 out of 8 species are typical of early to mid seral stages. However, there is a slight shift to a more perennial lifespan of the common species in high burn severity plots.

In conclusion, the analysis of plot constancies of the eight most common grasses and forbs per level of burn severity does not support the hypothesis that severely burned areas have appreciably more annual and biennial species and species established from seed than moderate or low severity burned areas two years after the 2005 School Fire. High and medium burn severity areas contain the same number of annual/biennial species and species originating from seed. Low burn severity areas contain about half of this amount. There is an apparent differential response to burn severity. In low burn severity areas, most of the common (perennial) species already present are likely to persist through vegetative regrowth and a few (annual) species may establish from seed, possibly from a seedbank. In medium burn severity areas about half of the common perennial species are those which continue to persist through resprouting. The other half of the species are annual/biennial species which originated from seed, some from the seedbank and some from offsite. In high burn severity areas, half of the common (perennial) species show a response in the form of vegetative regrowth. The other half is mostly annual/biennial and some perennial species, which probably established from seed that was transported to the site. Invasive species include annuals with easily dispersed seeds capable of dormancy as well as perennials which in addition have the ability to persist through resprouting. These species thus have characteristics similar to early successional native species and are able to invade areas of any level of burn severity.

Over time, the balances between annual and perennial species and those originating from sprouts versus seeds may shift as some species are lost through competition and others are gained through continued invasion. Also, the analysis is based on the plot constancies of only the eight most common species per level of burn severity. An examination of all species present in each burn severity class would provide a more comprehensive analysis. However, that is beyond the scope of this study.

IV. Conclusions

Two years after the 2005 School Fire, the three non-native invasive species present in the study area, *Cirsium arvense, Cirsium vulgare* and *Bromus tectorum,* are more abundant in high severity burn sites than in medium to low severity burn sites, as was hypothesized. Two growing seasons after the fire occurred in fall 2005, these species occur in less than 20% of high burn severity plots with a maximum percent cover of 2%. However, the potential for future invasion is high especially in high severity burn sites. Total vegetation canopy cover in these sites has not recovered, and there is still a substantial amount of bare ground (18% bare ground cover in high severity sites as compared to less than 3% bare ground in medium and low severity and control sites). Also, the response of native vegetation to high fire severity is moderate, so there is less competition from native species.

In contrast, native vegetation recovered rapidly on medium and low severity burns. Two years after the fire, canopy cover and percent bare ground are similar to that of unburned sites. Low to medium fire severity seems to stimulate forbs in particular, not only by increasing their percent cover but also by the recruitment of more species. Thus, competition is much stronger in these sites and the potential for invasion is greatly reduced. *Cirsium arvense*, *Cirsium vulgare* and *Bromus tectorum* may have established themselves immediately following the fire from seeds in the seedbank or from a source off site, or through vegetative regrowth (*Cirsium arvense*). However, they are likely to decline as native vegetation continues to recover. The perennial *C. arvense* may persist for a longer period of time.

High severity burn sites are not necessarily characterized by a greater number of annuals or plants from seeds than medium or low burn severity areas, contrary to our expectations. Common species in unburned sites are mostly perennials capable of vegetative regrowth as well as reproduction from seed. Annual forbs originating from seed first appear in low and in greater number in medium severity sites. Shrubs and grasses are somewhat more important than forbs in the recovery of high severity burn sites; high severity fire tends to increase the number of perennials. Therefore, in high severity burn sites more common species are perennials than in medium severity burn sites. About half of the species common in high burn severity sites likely originated from seed, which is the same as in medium burn severity sites. Remarkably, half of the common species in all fire-affected sites are perennials present in undisturbed sites, which presumably persist through vegetative regrowth.

In low to medium severity burn sites, the biennial *Cirsium vulgare* probably establishes from seed present in the seedbank, as does the native species *Claytonia perfoliata.* In high severity burn sites *C. vulgare* may also be established from wind-dispersed seed, since the seeds in the seedbank were likely destroyed by high severity fire. It occurs in all fire affected sites and its percent canopy cover increases with fire severity. *Cirsium arvense* and *Bromus tectorum* respond to fire with an increase in cover and abundance, similar to the native species *Epilobium angustifolium.* They are most successful in high severity burn sites, where they probably become established from off-site sources. Thus, non-native species share regeneration strategies with many native species characteristic of disturbed sites, which allows non-native plants to occupy niches otherwise occupied by native species and effectively compete with native vegetation.

V. Recommendations

The same characteristics which make *Cirsium arvense, Cirsium vulgare* and *Bromus tectorum* effective colonizers of burned sites (abundant seed production, easily dispersed seed, capacity for dormancy, seed germination stimulated by high light and temperature) also make it hard to control the spread of these non-native species post-burn. The results of this study indicate that fire is not an effective tool to eliminate these species. On the contrary, fire of any level of severity creates opportunities for these non-natives to become established and expand their area. However, measures that promote the response of native species such as restoring areas with seeding of native species will reduce the chance of invasion by non-native plants.

When prescribed burns are planned for other reasons, such as fuel level reduction, certain precautions can be taken to limit the spread of weeds. Prescribed burns should be conducted in early spring to prevent the development of high severity burns. Areas subjected to low and moderate severity burns are less likely to experience massive invasions of non-native species and recover more quickly. In addition, it would be useful to carry out preliminary surveys of established non-native plant populations and consider mechanical and/or chemical eradication of those populations which form an immediate threat to the area to be burned.

For fires resulting from lightning or human-caused fires, rehabilitation measures should be directed towards severely burned sites. Reseeding with early successional native species may be helpful in preventing weed invasions. Severely burned sites are often colonized from off-site seed sources. So, here again the spread of non- natives may be curtailed by eliminating existing populations of these species. However, in spite of these additional precautions, access roads, parking lots and other disturbed, open areas associated with human activity will probably continue to act as a refuge for non-native species, thereby ensuring their persistence.

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Table 1. Mean percent cover of tree canopy, bare ground, litter, and moss (± standard deviation,STD) and number of sites sampled (n), test statistic (Kruskal-Wallis test) and significance value (P) for differences among sites with high, medium, low and no fire (control) two years after the 2005 School Fire).

	Burn Severity					
Ground Layer	**High n = 8 Mean± STD**	**Medium n = 15 Mean± STD**	**Low = 15 Mean± STD**	**Control n = 4 Mean± STD**	χ^2	***P***
Tree Cover	17±9	29±13	31±12	31±10	7	0.06
Bare Ground	18±19	2±4	2±5	3±4	11	0.01
Litter	14±13	7±13	10±22	35±32	6	0.10
Moss	2±16	12±11	5±6	1±1	9	0.03

Table 2. Pairwise significant differences for species and cover types among high, medium, and low burn severities and control two years after the 2005 School Fire).

Species/cover type	Pairwise Differences[1]	
Canopy Cover	High vs Control	High vs Low
Bare ground	High vs Low	High vs Medium
Moss	High vs Control	
CIVU	High vs Control[2]	
CAGE	High vs Control[2]	
EPAN	Low vs Medium	
LASE	High vs Low	High vs Control
CLPE	Low vs Medium[2]	Medium vs Control[2]
STELL	Medium vs Control[2]	
SALIX	Medium vs Control	
SASC	High vs Low[2]	High vs Control[2]

[1] Pairwise comparison error rate *P*=0.05; exceptions are noted
[2] Pairwise comparison error rate *P*=0.10

Table 3. Mean percent canopy cover of grasses, forbs, shrubs, and trees (seedlings) (±standard deviation,STD) and number of sites sampled (n), test statistic (Kruskal-Wallis test) and significance value (P) for differences among fire intensities and control sites two years after the 2005 School Fire.

	Fire severity					
	High n = 8	**Medium n = 15**	**Low n = 15**	**Control n = 4**		
Physiognomic Layer	**Mean ± STD**	**Mean ± STD**	**Mean ± STD**	**Mean ± STD**	χ^2	***P***
Grasses	11±19	12±18	5±5	3±4	1.41	0.7
Forbs	16±9	32±17	29±14	25±23	6.98	0.07
Shrubs	12±7	7±6	8±6	6±5	3.12	0.37
Trees (Seedlings)	1±1	1±1	1±2	5±0	5.96	0.11

Table 4. Mean percent canopy cover for non-native invasive species, common grasses, forbs, and shrubs per site (mean cover/site), standard deviation (STD) and number of sites sampled (n), test statistic (Kruskal-Wallis test) and significance value (P) for differences among burn severities and control sites two years after the 2005 School Fire. Bolded rows indicate species which differed significantly in percent cover among low, medium, high severity, and control sites.

	Fire severity and number of sites (n)					
	High n = 8	***Medium n= 15***	***Low n= 15***	***Control n = 4***		
Species[1]	***Mean ± std***	***Mean ± std***	***Mean ± std***	***Mean ± std***	χ^2	***P***
Invasive						
CIAR (forb)	1 ±2	0 ± 1	0	0	3.75	0.28
CIVU (forb)	**2 ± 2**	**2 ± 2**	**1 ± 1**	**0**	**7.12**	**0.06**
BRTE (grass)	0	1 ± 2	0	0	2.75	0.43
Common Grasses						
FEID	2 ± 4	2 ± 5	1 ± 1	0 ± 1	0.3	0.95
CAGE	**0**	**0± 1**	**2 ± 2**	**2 ± 4**	**11.9**	**0.01**
CARO	1 ± 2	0± 1	0 ± 1	0	0.61	0.89
BRCA	3 ± 6	2 ± 6	0± 1	0	5.2	0.16
Common Forbs						
ARCO	2 ± 3	4± 5	6± 5	5± 3	4.17	0.24
EPAN	**3 ± 5**	**3 ± 3**	**0± 1**	**0**	**9.43**	**0.02**
LASE	**1 ± 1**	**2± 4**	**0**	**0**	**13.89**	**<0.01**
CLPE	**0**	**8± 13**	**4± 5**	**0**	**11.08**	**0.01**
ACMI	0 ± 1	1± 2	2± 3	0± 1	0.78	0.85
STELL	**1± 1**	**2± 3**	**0± 1**	**0**	**7.49**	**0.05**
ANEMO	0	1± 1	1± 1	1± 1	3.88	0.27
Common Shrubs						
SALIX	**2± 6**	**3± 3**	**1± 2**	**0**	**10.6**	**0.01**
SPBE	1± 2	1± 2	2± 2	1± 1	4.01	0.25
SASC	**6± 7**	**1± 2**	**0± 1**	**0**	**14.12**	**<0.01**

[1)]For species code see Appendix B.

Table 5. Species richness (number of species) for each level of burn severity and physiognomic layer two years after the 2005 School Fire.

	Fire Severity			
	High	**Medium**	**Low**	**Control**
Grasses	13	15	15	5
Forbs	33	51	65	36
Shrubs	11	16	14	7
Trees	4	5	6	3
Total	61	87	100	51

Table 6. Presence of non-native invasive species and the eight most common species in each of the four physiognomic layers based on % constancy per plot (Const.1) and per site (Const. 2). Cover is the average % cover per sampled plot two years after the 2005 School Fire.

Physiognomic Layer	Species	Const. 1	Const. 2	% Cover
Grasses	FEID	24	55	1
	CAGE	16	40	1
	CARO	14	35	0
	BRCA	10	28	1
	ELGL	9	19	1
	POSE	7	19	1
	UGRASS	6	20	1
	AGSP	5	14	0
Invasives	CIVU	15	54	1
	CIAR	6	20	0
	BRTE	4	19	0
Forbs	ARCO	46	86	5
	EPAN	32	62	2
	LASE	31	65	1
	CLPE	24	55	3
	ACMI	21	51	1
	STELL	19	60	1
	ANEMO	18	51	0
Shrubs	SALIX	24	51	2
	SPBE	23	55	1
	SASC	18	31	1
	ROSA	8	28	1
	RIBES	8	29	0
	SYAL	7	17	1
	RIVI	6	17	0
	VACCI	4	14	0
Trees	PSME	25	55	1
	ABGR	19	43	0
	PIPO	13	40	0
	PIEN	5	19	0
	UTREE	3	8	0
	LAOC	1	5	0

Table 7. Plot constancy of the eight most common species of grasses and forbs (numbers bolded) and three species of shrubs organized by level of fire severity, and life span and regeneration strategy of each species two years after the 2005 School Fire.

	Fire severity					
Species[1)]	High	Medium	Low	Control	Life span[2)]	Regeneration Strategy
CAGE	0	7	23	**65**	P	V
ARCO	**35**	**33**	**57**	**60**	P	v/s
ANEMO	8	20	**25**	**35**	P	v/s
ANPI	8	9	5	**15**	P	v/s
HIAL	3	1	5	**20**	P	v/s(b)
FEID	**25**	**23**	**24**	**20**	P	v/s
THOC	0	3	**15**	15	P	v/s
ACMI	**20**	**23**	**28**	**20**	P	v/s
CLPE	5	**36**	**31**	0	A/P	s(b)
STELL	10	**23**	**24**	0	A/P	v/s
EPMI	0	**21**	12	5	A	s(b)
CIVU	**18**	20	16	0	A/B	s(b)
EPAN	**53**	**37**	**15**	**15**	P	v/s
LASE	**53**	**43**	12	0	A/B	S
BRCA	**23**	11	5	0	A/P	v/s(b)
ELGL	**23**	16	1	0	P	s
BRTE	8	1	1	0	A	s(b)
CIAR	13	7	2	6	P	v/s(b)
SALIX	8	**43**	24	0	P	v/s
SASC	**58**	8	8	0	P	v/s
SPBE	10	15	**29**	15	P	v

[1] For species codes see Appendix B.
[2] Life span: A – Annual, P – Perennial, and B – Biennual.
[3] Regeneration Strategy: v – vegetative regrowth, s – regeneration predominantly from seed, and b – exhibits dormancy (seedbank)
[2,3] Data from : Fire Effects Information System (http://www.fs.fed.us/database/feis/) and USDA NRCS (2009).

Appendix A.
Number of sites sampled at High, Medium, and Low burn severity and subsequently treated (Salvaged, Seeded, Salvaged and Seeded, or No Treatment; two years after the 2005 School Fire). Note: only sites without any treatment (bolded column) were sampled.

	Treatment				
Burn Severity	Salvaged	Seeded	Seeded and Salvaged	**None**	Total
High	3	2	2	**8**	15
Medium	8	-	-	**15**	23
Low	8	-	-	**15**	23
No Burn (Control)	-	-	-	**4**	4
Total	19	2	2	**42**	65

Appendix B. List of Species and their code used in this study

ABGR	*Abies grandis*
ACMI	*Achillea millefolium*
AGSP	*Agropyron spicatum*
ANEMO	*Anemone* spp.
ANPI	*Anemone piperi*
ARCO	*Arnica cordifolia*
BRTE	*Bromus tectorum*
BRCA	*Bromus carinatus*
CAGE	*Carex geyeri*
CIVU	*Cirsium vulgare*
CIAV	*Cirsium arvense*
CLPE	*Claytonia perfoliata*
ELGL	*Elymus glaucus*
EPAN	*Epilobium angustifolium*
EPMI	*Epilobium minutum*
FEID	*Festuca idahoensis*
HIAL	*Hieracium albiflorum*
LAOC	*Larix occidentalis*
LASE	*Lactuca serriola*
PIEN	*Picea engelmannii*
PIPO	*Pinus ponderosa*
POSE	*Poa secunda*
PSME	*Pseudotsuga menziesii*
ROSA	*Rosa* spp.
RIBES	*Ribes* spp.
RIVI	*Ribes viscosissimum*
SALIX	*Salix* spp.
SASC	*Salix scouleriana*
SPBE	*Spiraea betulifolia*
STELL	*Stellaria* spp.
SYAL	*Symphoricarpos albus*
THOC	*Thalictrum occidentale*
UGRASS	Unknown grass
UTREE	Unknown tree
VACCI	*Vaccinium spp.*