RESEARCH NOTE

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Rehabilitating Slash Pile Burn Scars in Upper Montane Forests of The Colorado Front Range

Paula J. Fornwalt[1,2]

[1]USDA Forest Service
Rocky Mountain Research Station
240 West Prospect Road
Fort Collins, Colorado 80526

Charles C. Rhoades[1]

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[2] Corresponding author:
pfornwalt@fs.fed.us

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ABSTRACT: Slash pile burning is widely conducted by land managers to dispose of unwanted woody fuels, yet this practice typically has undesirable ecological impacts. Simple rehabilitation treatments may be effective at ameliorating some of the negative impacts of pile burning on plants and soils. Here, we investigated: (1) the impacts of slash pile burning on soil nitrogen and understory plant species richness and cover in Colorado *Pinus contorta* Douglas ex Louden and *P. contorta – Populus tremuloides* Michx. stands; (2) the effectiveness of woodchip mulch and soil scarification at reversing pile burning impacts on soil nitrogen; and (3) how mulching and scarifying, alone and in conjunction with native grass seeding, promote native plant establishment and discourage exotic invasion in burn scars. We found that pile burning diminished native richness and cover and increased soil nitrogen, particularly in the interior of burn scars where fire severity was greatest. Rehabilitation treatments appear to be useful tools for reversing pile burning impacts on soil and plants. Mulching dampened the increase in soil nitrogen; and scarifying, scarifying plus seeding, and mulching plus seeding were effective at encouraging native plant development while simultaneously minimizing exotic plant colonization.

Index terms: exotic plants, pile burning, rehabilitation techniques, soil nitrogen, understory

INTRODUCTION

Slash pile burning is a common land management activity for disposing of woody residue, yet the extreme soil temperatures generated beneath burning piles typically have undesirable impacts on established understory plants, seedbanks, soil biota, and soil chemical and water-holding properties (Covington et al. 1991; Esquilin et al. 2007; Massman et al. 2008). Consequently, native plant recovery in burn scars is often delayed for years (Korb et al. 2004), although the scars can become sites of exotic plant invasion (Haskins and Gehring 2004). Nevertheless, alternatives to pile burning remain limited; broadcast burning is often restricted by air quality regulations and risk of fire escape, for example, while mechanical mastication remains a relatively new and untested practice (Battaglia et al. 2009). Land managers must, therefore, balance the practicality of pile burning with its ecological costs.

Simple rehabilitation treatments may be useful tools for ameliorating some of the negative impacts of pile burning. Seeding scars should encourage native plant establishment by replenishing the seedbank (Korb et al. 2004). Mulching may benefit reestablishing plant communities in scars by conserving soil moisture and moderating summer soil temperatures (Binkley et al., unpubl. data; Miller and Seastedt 2009). Mulching may also reduce plant-available soil nitrogen (N), at least temporarily (Binkley et al., unpubl. data), and thereby potentially discourage the establishment of weedy species with high N demand (Zink and Allen 1998). Soil scarification may favor plant establishment by improving water infiltration in burn scars (Robichaud et al. 2003).

Here, we examined the influence of slash pile burning on soils and plants in three upper montane forest stands of the Colorado Front Range, and we compared the relative effectiveness of mulching, scarifying, and seeding at rehabilitating slash pile burn scars. Specifically, our objectives were to: (1) identify the impacts of pile burning on soil N and on native and exotic understory species richness and cover; (2) examine the effectiveness of mulching and scarifying at reversing pile burning impacts on soil N; and (3) determine how mulching and scarifying, alone and in conjunction with native grass seeding, promote native plant establishment and discourage exotic invasion in burn scars.

METHODS

Study sites

We established three study sites at Reynolds Ranch, a 348-ha property near Nederland, Colorado, that is owned and managed by Boulder County Parks and Open Space. Forest overstories at the sites are dominated by *Pinus contorta* Douglas ex Louden (lodgepole pine) or *P. contorta* and *Populus tremuloides* Michx. (quaking aspen). Topography is gently rolling, with elevations ranging from 2600-2650 m. Soils are sandy, gravelly, and stony loams (http://websoilsurvey.nrcs.usda.

gov). Precipitation in Nederland averages 46 cm annually (http://www.wrcc.dri.edu). Stands were thinned by hand in the summer of 2005 or 2006, and the thinned material was placed in piles 2-10 m in diameter. Piles were burned in the winter of 2006-07 or 2007-08.

Rehabilitation treatments

In June 2008, three surface treatments – untreated control, soil scarification, and woodchip mulch – were applied to burn scars (Figure 1). Surface treatments were assigned to scars by grouping scars into blocks of three and randomly designating one treatment to each. Three to six blocks were established at each site, with 14 blocks in total. Scars within blocks were selected to be comparable in terms of topography, soil, size, burn severity, and the composition of the surrounding vegetation. Mulched scars received a 4-6 cm layer of chipped woody material. Scarified scars were raked to a depth of 8-10 cm using a McLeod fire tool.

Half of each scar was also seeded with native perennial grasses at a rate of 80 seeds m^{-2}. *Elymus elymoides* (Raf.) Swezey (squirreltail) constituted 14% of the seed mix, while *Elymus trachycaulus* (Link) Gould ex Shinners 'San Luis' (San Luis slender wheatgrass) and *Muhlenbergia montana* (Nutt.) Hitchc. (mountain muhly) made up 36% and 50% of the mix, respectively. The seeds were spread by hand and gently tamped into the soil. Seed was applied prior to mulching but after scarification.

Data collection and analysis

Sampling occurred at six locations per scar, along transects that extended from outside the burn scar on the seeded side, through the scar center, to outside the scar on the unseeded side. Two sampling locations were in the scar interior (one on the seeded side of the scar and the other on the unseeded side) – two were just inside the scar edge, and two were 1 m outside the scar.

Plant-available soil N was assessed at the sampling locations using ion exchange resin (IER) bags (Binkley and Matson 1983). Bags were inserted 5-10 cm into the mineral soil in June 2008 to sample nitrate (N_{O3}-N) and ammonium (NH_4-N) as they percolate through the mineral soil. To characterize seasonal patterns in N availability, bags were removed in November 2008 and a new set of bags was installed. The second set of bags was removed in May 2009. Bags were stored at 5 °C until the resins could be extracted with 100 mL of 2 M KCl and analyzed by spectrophotometry (Latchat Instruments, Milwaukee, WI).

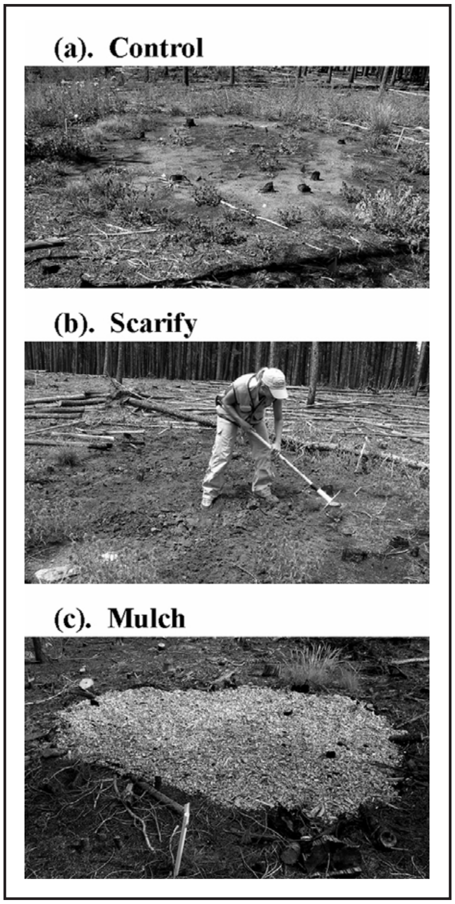

Figure 1. Slash pile burn scar surface rehabilitation treatments included: (a) untreated control, (b) soil scarification, and (c) woodchip mulch. Half of each pile was also seeded with native grasses.

At the end of the 2008 and 2009 growing seasons, we visually estimated plant cover by species in 0.25 m^2 (0.5 m x 0.5 m) subplots at the sampling locations. Cover estimates were made to the nearest percent. Nomenclature and species nativity follow the USDA-NRCS Plants Database (2009). Native and exotic species richness per subplot were subsequently calculated by counting the number of native/exotic species, while native and exotic cover per subplot were calculated by summing the cover of each. In each subplot we also estimated the cover of soil, rock, litter, duff, wood, and ash.

Slash pile burning and rehabilitation treatment impacts on soil and plant variables were evaluated using mixed model analysis of variance (ANOVA) in SAS (SAS Institute, Cary, NC). Statistical significance was assessed at $\alpha = 0.05$. Significant variables were further examined for pairwise differences using least squares means with Tukey-Kramer adjustments for multiple comparisons. N data were log transformed, richness data were square-root transformed, and cover data were arcsin square-root transformed to approximate ANOVA assumptions of residual normality and homoscedasticity.

RESULTS AND DISCUSSION

Slash pile burning impacts on soils and plants

As seen elsewhere (Covington et al. 1991; Korb et al. 2004), untreated slash pile burn scars were characterized by significantly more bare soil and ash than surrounding unburned areas. These effects were most pronounced in untreated scar interiors. Combined soil and ash cover in scar interiors exceeded 55% in both 2008 and 2009, while at the edges of untreated scars it exceeded 35%. In contrast, less than 10% of the ground surface was characterized by soil and ash in surrounding unburned areas. Left untreated, the soil exposed during pile burning may persist for years (Covington et al. 1991; Rhoades et al. 2004).

Slash pile burning has been shown to cause an immediate increase in plant-available soil ammonium (Covington et al. 1991; Wan et al. 2001); our results are consistent with these findings. Averaged across the 2008 summer and 2008/2009 winter/snowmelt sampling periods, we found that IER-ammonium was 2.3-fold higher in untreated scar interiors and 1.4-fold higher at untreated scar edges compared to the surrounding unburned area. Soil nitrate also typically increases after burning, but often lags weeks or months as nitrifying bacteria respond to the increase in ammonium and soil pH (Certini 2005). Our results indicate that IER-nitrate was ~2.0-fold higher in untreated burn scar interiors and edges, and comprised a similar amount of the total pool of plant available N inside and outside of the burn scars (i.e., 68% and 71%, respectively). Soil N pools usually return to prefire levels two to five years after burning as plant and microbial N uptake deplete these labile soil resources (Covington et al. 1991; Esquilin et al. 2007).

Native understory plant species in Rocky Mountain forests are typically fire-adapted (Turner et al. 1999; Stickney and Campbell 2000), yet the soil temperatures that occur during pile burning can be considerably greater than those created by even the most severe wildfires (Massman et al. 2008). These extreme temperatures are likely responsible for the greatly diminished values of native richness and cover we observed in the interior of untreated burn scars (Figure 2). In both 2008 and 2009, we noted little to no native plant establishment from surviving roots and rhizomes in the center of scars where fire temperatures were probably greatest; rather, establishment was primarily from seeds that either survived in the soil or dispersed in from surrounding areas. Native species commonly encountered in the interior of untreated scars included the early successional species *Chenopodium leptophyllum* (Moq.) Nutt. ex S. Watson (narrowleaf goosefoot), *Corydalis aurea* Willd. (scrambled eggs), and *Phacelia heterophylla* Pursh (*varileaf phacelia*). In contrast, the lower fire temperatures that likely occurred at the scar edge allowed for native plant establishment from surviving belowground organs and from seed; as a result, native richness and cover at untreated scar edges were comparable to levels found outside the scars (Figure 2).

While exotic plants often establish after pile burning due to elevated soil resources and exposed soil (Haskins and Gehring 2004; Korb et al. 2004), we found that exotic richness and cover were no higher in untreated scars than in surrounding unburned areas in either 2008 or 2009 (Figure 2). However, the presence of several noxious weed species at our sites, including *Cirsium arvense* (L.) Scop. (Canada thistle) and *Verbascum thapsus* L. (common mullein), suggests that exotics may spread into scars if scars are left untreated. These species can aggressively invade Colorado forests following wildfire (Fornwalt et al. 2010).

Surface treatment effectiveness at reversing pile burn effects on soil N

We found that a 4-6 cm layer of wood mulch helped reverse the increase in soil N created by pile burning (Figure 3); averaged across the summer and winter/snowmelt seasons, mulching reduced IER-ammonium by 55%-80% in scars, and reduced IER-nitrate by 40%-50%. The influence of mulching on soil N also varied seasonally; the amount of total IER-N, IER-ammonium, and IER-nitrate beneath mulch was considerably lower during the winter/snowmelt season than the summer season (Figure 3). This contrasts with seasonal trends in untreated scars and in surrounding unburned areas, where all forms of IER-N were higher during the winter/snowmelt period. Decreases in soil N have also been found in coniferous forests of Colorado where masticated woody material was broadcast on the forest floor

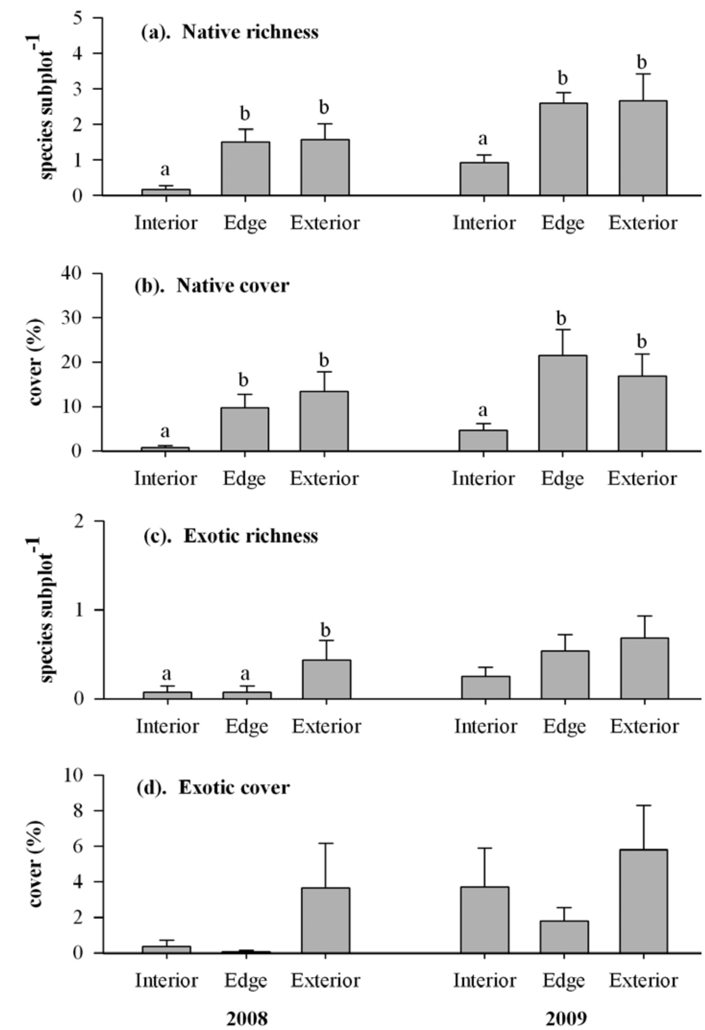

Figure 2. Mean (± standard error) plant properties in untreated pile burn scar interiors and edges, and in adjacent unburned areas. Significant differences among sampling locations for a given year are indicated by different letters.

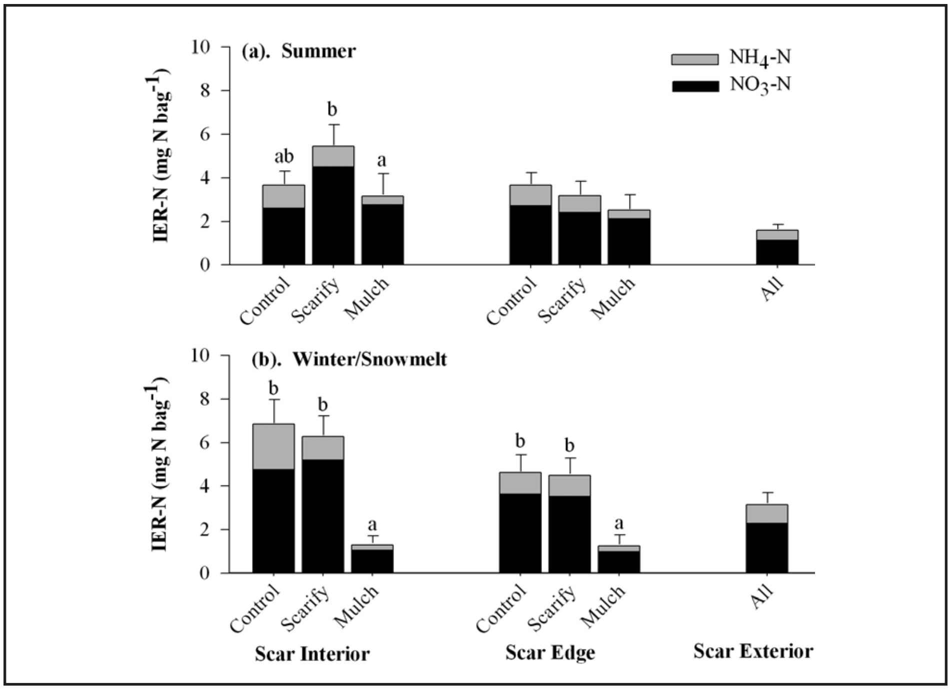

Figure 3. Surface rehabilitation treatment impacts on plant-available ammonium and nitrate measured with ion exchange resins (IER). Data are means ± standard errors. Different letters identify significant treatment effects on total IER-N within a sampling location.

(Binkley et al., unpubl. data; Battaglia et al. 2009). Wood mulch can reduce soil N by providing soil microbes with a readily-available carbon source to stimulate their growth and uptake of soil N (Eschen et al. 2007). Soil N reductions may persist for months to years following the addition of mulch or other carbon sources (Reever-Morgan and Seastedt 1999).

Scarification is becoming increasingly used to rehabilitate soils after severe wildfire (e.g., Robichaud et al. 2003), but its utility in areas degraded by pile burning was previously unexplored. In contrast to mulching, we found that scarification doubled IER-nitrate and increased total IER-N 1.7-fold relative to untreated burn scars (Figure 3). Scarification had no effect on IER-ammonium. Seasonal trends in N also contrasted greatly between mulching and scarifying, with N in scarified burn scars increasing by about 50% during the 2008/2009 winter/snowmelt period relative to the summer 2008 period. Other research in Colorado has also shown that scarification alters soil N pools and that effects persist for 25 years (Esquilin et al. 2008).

Influence of surface and seeding treatments on plant communities

In scar interiors, three treatments – scarifying, scarifying plus seeding, and mulching plus seeding – all significantly increased native plant richness and cover by the 2009 measurement period (Figure 4). Indeed, the greatest native response was observed in mulched-and-seeded areas, where native richness was 3.4-fold higher and native cover was 4.6-fold higher than controls. While mulching alone may form a barrier to seeds dispersing in from the surrounding area, seeding prior to mulching likely ensured good soil-seed contact. The mulch may have also encouraged seeded grass germination by elevating soil moisture and moderating soil temperature fluctuations (Miller and Seastedt 2009). In contrast, scarification may have favored native plants by disrupting water repellant soil layers and increasing soil surface roughness, thereby increasing water availability (Robichaud et al. 2003). The combination of scarifying and seeding may have further benefited natives by allowing for greater seed retention on the roughened soil surface. Treatments did not alter native plant richness or cover at scar edges relative to controls, although some differences among treatments were observed.

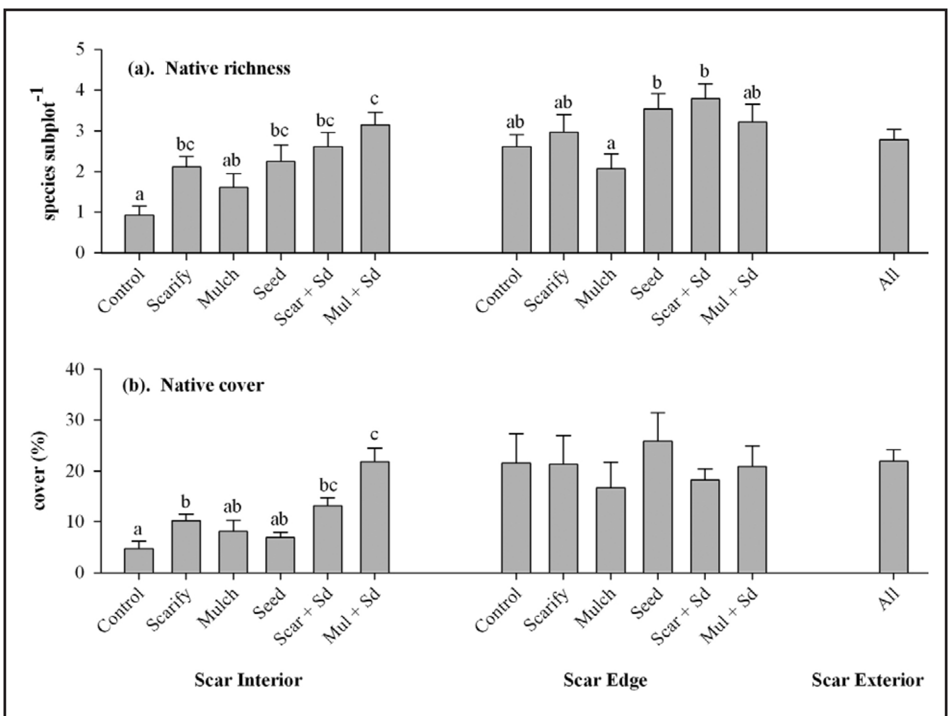

Figure 4. Impacts of surface and seeding rehabilitation treatments on native plants in burn scars. Data are 2009 means ± standard errors. Different letters indicate significant differences among treatments within a sampling location. "Scar + Sd" refers to the scarification plus seed treatment, while "Mul + Sd" refers to mulch plus seed.

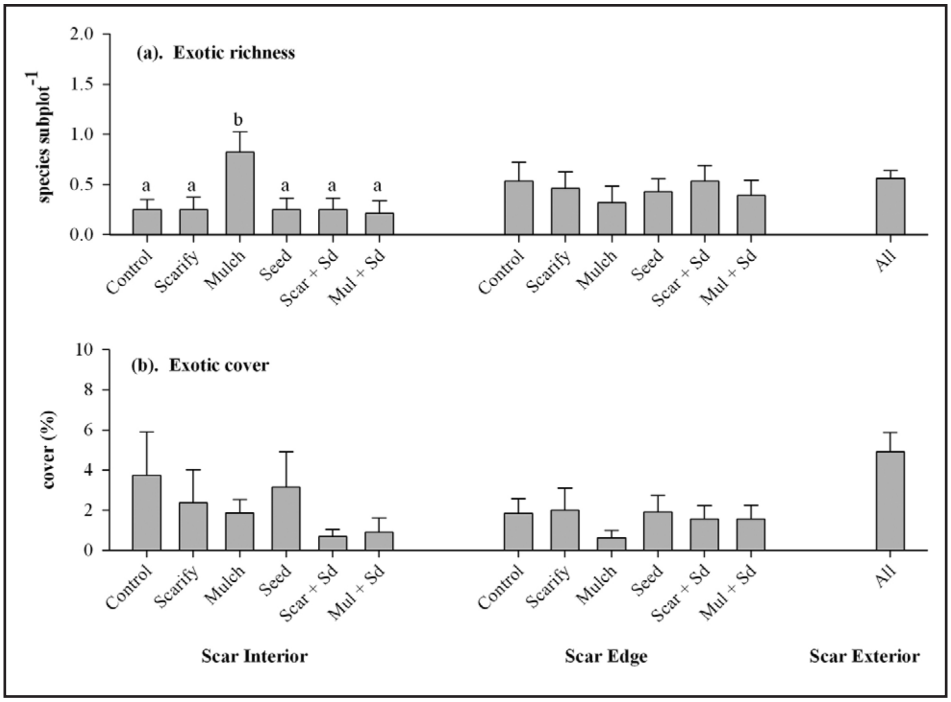

Figure 5. Surface and seeding treatment impacts on mean 2009 exotic richness and cover (± standard error) in burn scars. Different letters indicate significant differences among treatments within a sampling location. "Scar + Sd" refers to the scarification plus seed treatment; "Mul + Sd" refers to mulch plus seed.

Our 2009 data indicate exotic plants were largely unimpacted by rehabilitation treatments (Figure 5). Only mulching influenced exotic levels, resulting in increased exotic richness in scar interiors relative to untreated controls. Mulching, however, did not influence exotic cover, nor did it impact exotic richness at scar edges, and so we are reluctant to draw any firm conclusions.

Elymus trachycaulus was the most successful of the three seeded grass species, accounting for nearly 80% of total seeded grass cover in 2009 (Figure 6). *E. trachycaulus* was particularly successful under mulch. Petersen et al. (2004) also found that *E. trachycaulus* was a superior species for revegetating road cuts in Utah. However, seeded *E. trachycaulus* populations usually decline after a few years, and so it is generally recommended that seed mixes containing *E. trachycaulus* also contain longer-lived species (USDA-NRCS 2009). Our mix also contained *E. elymoides* and *Muhlenbergia montana*, which germinated readily in the scars, although plants were small. It is likely that these species will increase in cover as *E. trachycaulus* declines.

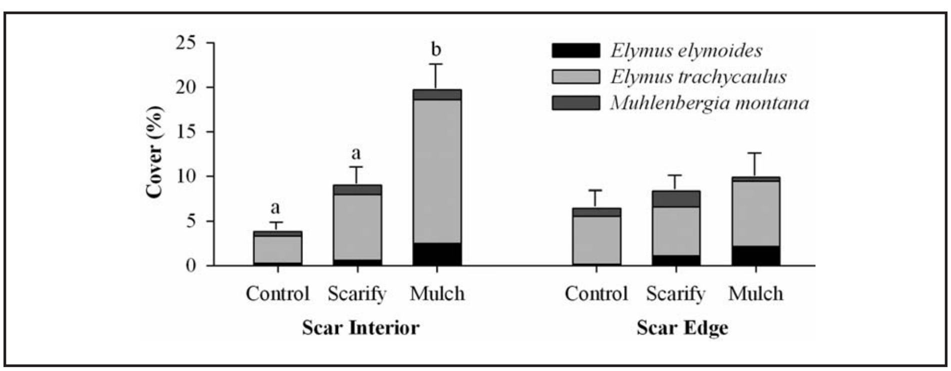

Figure 6. Mean 2009 seeded grass cover (± standard error) in the seeded halves of control, scarified, and mulched burn scars. Different letters indicate significant differences in total seeded grass cover among surface treatments within a sampling location.

IMPLICATIONS FOR MANAGEMENT

Managers often conduct slash pile burning due to its practicality, despite the negative ecological impacts described here and elsewhere (e.g., Covington et al. 1991; Haskins and Gehring 2004; Korb et al. 2004). Fortunately, our results suggest that simple treatments may be useful for ameliorating the effects of pile burning on plants and soils. Of the treatments we studied, mulching reduced the increase in soil N caused by pile burning; scarifying, scarifying plus seeding, and mulching plus seeding were effective at encouraging native plant development while simultaneously minimizing exotic plant colonization. However, the short time frame of this study and the limited number of study sites prevents broad generalization of our findings. Therefore, we recommend that managers who attempt to rehabilitate pile burn scars closely monitor and adjust treatments as necessary.

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Paula Fornwalt is a Research Ecologist with the USDA Forest Service's Rocky Mountain Research Station. Paula's research investigates the impacts of natural and human disturbances on plant populations and communities in Rocky Mountain ecosystems.

Chuck Rhoades is a Research Biogeochemist with the USDA Forest Service's Rocky Mountain Research Station. Chuck studies the effect of natural and human disturbances on nutrient cycling, soil, and water quality in forests of the Rocky Mountains.

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