Slash pile burn scar restoration in montane forests of Boulder County, Colorado

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Abstract

Slash pile burning is a widespread fuels reduction treatment because of its practicality and cost-effectiveness, yet it often has undesirable impacts on soils and plants in the burned area. Simple slash pile scar treatments may be sufficient to alter soil properties in favor of native species establishment. This final report details our progress on two separate yet related research projects that are examining the impacts of slash pile burning on plants and soils, and the effectiveness of restoration treatments at reestablishing plants and restoring soil properties within scars.

The first project was initiated in 2008 in upper montane forest sites dominated by *Pinus contorta* (lodgepole pine) and/or *Populus tremuloides* (aspen). Six slash pile scar restoration treatments were installed at the sites in June 2008: (1) scarifying the soil surface; (2) mulching with chipped woody material; (3) seeding with native species; (4) scarifying + seeding; (5) mulching + seeding; and (6) untreated control. Plants and soils data were collected in July 2008 and July 2009. The second project was initiated in 2009 in lower montane sites dominated by *Pinus ponderosa* (ponderosa pine) and/or *Pseudotsuga menziesii* (Douglas-fir). In October-November 2009, eight slash pile scar restoration treatments were installed: (1) scarifying, (2) slash mulching by layering woody branches on the scar surface; (3) mulching; (4) seeding with native species; (5) scarifying + seeding; (6) slash mulching + seeding; (7) mulching + seeding; and (8) untreated control. Plants and soils data collection will begin in the lower montane sites in 2010.

Results from upper montane forests indicate that slash pile burning diminished understory plant richness and cover in upper montane forests of Boulder County over the short term (1-2 growing seasons after burning). This effect was most pronounced in the interior of pile scars, where the fire burned hottest. The decrease in richness and cover occurred despite the fact that the burning greatly increased the amount of plant-available nitrogen in the scars. Our results also indicate that restoration treatments further impacted plants and soils in slash pile scars. Relative to untreated pile scars, mulching decreased soil nitrogen and increased native richness and cover in the interior of scars, but also increased exotic richness. In contrast, scarification increased soil nitrogen and native richness and cover in scar interiors, but had no impact on exotics. Seeding native species into slash pile scars directly increased native richness and cover and decreased exotic cover in scar interiors. Furthermore, in scar interiors the combination of mulching plus seeding generated the highest levels of native richness and cover. Native richness and cover values observed in mulched and seeded interior subplots were nearly two times greater than those observed in the control scars, and were on par with values observed in unburned areas outside the pile scars. Of the three perennial grass species used in our seeding treatments, *Elymus trachycaulus* (slender wheatgrass) was by far the most successful in terms of cover. These results suggest that mulching and seeding slash pile scars in upper montane forests of Colorado may help managers restore prefire soil properties, encourage native plant community development, and also possibly reduce exotic invasion. The applicability of our findings to lower montane forests remains unknown at this point.

Introduction

Land managers throughout western North America are increasingly implementing fuels reduction treatments to decrease tree densities on forest lands. In some areas, these fuels reduction treatments are being used to minimize the risk of high severity wildfire within the wildland-urban interface (Hirsch and Pengelly 2000; Kalabokidis and Omi 1998); in areas where a century of fire suppression has increased forest density, fuels reduction treatments are being used to restore ecologically appropriate and sustainable forest stand conditions (Kaufmann et al. 2005). Regardless of the management objective, options for reducing woody fuels remain limited (Wolk and Rocca 2009). Traditional timber harvests generally are not economically feasible for fuels reduction because much of the removed material is typically small and unmerchantable. The use of prescribed fire is often restricted by air quality regulations and the risk of fire escape.

One practical and cost-effective fuels reduction treatment that is widely used by managers is piling the thinned woody material and burning it on site. However, slash pile burning often has undesirable ecological impacts. The extreme soil temperatures encountered under burning slash piles generally kill all living vegetation, as well as all viable seeds in the soil seed bank and beneficial soil biota such as mycorrhizae (Esquilin et al. 2007; Korb et al. 2004). The extreme temperatures can also negatively impact physical and chemical soil properties that are important for successful native establishment (Esquilin et al. 2007; Korb et al. 2004; Massman et al. 2008). Consequently, native plant recovery is often delayed for many years following pile burning (Korb et al. 2004). The unsightly scars, however, can become hotspots for exotic plant invasion and soil erosion (Haskins and Gehring 2004; Korb et al. 2004; Wolfson et al. 2005). Given the widespread use of pile burning, it is important to develop effective methods of rehabilitating burned slash pile scars so that their impacts on soil properties and plant communities can be minimized.

Simple restoration treatments may be sufficient to alter soil properties in favor of native species establishment. Seeding the surface of the scar with an ecologically appropriate mix of native species can directly encourage native plant establishment by reintroducing a soil seed bank (Korb et al 2004). Mulching treatments may indirectly encourage native establishment in scars by increasing soil moisture and by moderating summer soil temperatures (Binkley et al. 2003). Mulching may also enhance soil fertility as the mulch decomposes, though in the short term, available nitrogen may be reduced in mulched sites (Battaglia et al. in review; Binkley et al. 2003; Rhoades et al. in preparation). Scarifying treatments may encourage native establishment by disrupting water repellant layers present in slash pile scars (Larsen et al. 2009; C. Rhoades personal observation), and by mixing nutrients contained within the ash layer into the mineral soil.

This final report details our progress on two separate yet related research projects that are examining the impacts of slash pile burning on plants and soils, and the effectiveness of restoration treatments at reestablishing plants and restoring soil properties within scars. The first project was initiated in 2008 in upper montane forests dominated by *Pinus contorta* (lodgepole pine) and/or *Populus tremuloides* (aspen). The second project was initiated in 2009 in lower montane forests dominated by *Pinus ponderosa* (ponderosa pine) and/or *Pseudotsuga menziesii*

(Douglas-fir). For both projects, our research objectives were (1) to determine the effects of slash pile burning on understory plants and on soil properties that are important for plant establishment and growth; (2) to examine the effectiveness of various slash pile scar restoration treatments at restoring pre-fire soil properties, reestablishing native species, and reducing exotic species within the scars; and (3) to identify which native understory species, when seeded into slash pile scars, have the greatest establishment and growth success.

Upper montane forests: Reynolds Ranch

Methods

Study area and study sites

Our study was conducted at Reynolds Ranch, a 348 ha property located just outside the town of Nederland, Colorado (Figure 1). Reynolds Ranch has been owned and managed by Boulder County Parks and Open Space (BCPOS) since 1999. Forests here are dominated by *Pinus contorta* (lodgepole pine) and/or *Populus tremuloides* (aspen). *Achillea millefolium* (common yarrow), *Arctostaphylos uva-ursi* (kinnikinnick), and *Carex* (sedge) sp. are common forb, shrub, and graminoid species, respectively. Topography is flat to rolling in the portions of Reynolds Ranch we sampled, with elevations ranging from 2600 to 2650 m. Soils are sandy, gravelly, and/or stony loams formed from weathered igneous and metamorphic rock, and are very well-drained (http://websoilsurvey.nrcs.usda.gov). Precipitation in Nederland averages 46 cm annually, most of which falls during the spring and summer (http://www.wrcc.dri.edu). January is the coldest month, with average highs of 1.6°C and average lows of -11.7°C; the warmest temperatures occur in July, when maximum daytime temperatures average 24.0°C (http://www.wrcc.dri.edu).

We established three study sites at Reynolds Ranch (Table 1). The Powerline site is located in a *P. contorta* stand that was thinned in the summer of 2005. The thinned material was immediately piled, and the piles were burned in the winter of 2007-2008. The Old site is in the same thinned stand as the Powerline site, but piles were burned in the winter of 2006-2007. The Aspen site is located in a *P. contorta – P. tremuloides* stand that was thinned and piled in the summer of 2006; piles were burned in the spring of 2008. Slash pile scar diameters range from 3.6 m at the Aspen site to 4.1 m at the Old site and 6.4 m diameter at the Powerline site.

Restoration treatments

Because abiotic and biotic conditions were often variable within a site, we grouped slash pile scars into blocks of three scars each. All scars within a block were as comparable as possible in terms of topography, soils, size, and the composition of the surrounding understory and overstory. We then randomly applied one of three treatments to each slash pile scar in a block (Figure 2). Slash pile scars receiving the scarification treatment were raked by hand to a depth of 8-10 cm with a McLeod. For slash pile scars receiving the mulch treatment, we applied a 4-6 cm layer of local chipped woody material. Control scars were left untreated. We collectively refer to the scarification, mulching, and control treatments as “surface treatments” because they directly manipulate the surface of the pile scars. Surface treatments were installed in June 2008.

Half of each pile scar also received a seeding treatment. The seed mix used in the seeding treatment contained three native perennial grass species and was applied in June 2008 at a rate of 80 seeds m^{-2} (Table 2). The seeds were mixed with sand and spread by hand to ensure even seed distribution, then gently tamped into the soil with a McLeod. Where scars were also mulched or scarified, the seed was applied prior to mulching but after scarification. If a slash pile scar was on sloping terrain, we applied the seed to the downhill half of the scar to avoid potential contamination caused from seed washing out of the seeded scar half and into the unseeded scar half. On flat terrain, we randomly assigned the seeding treatment to scar halves. The noxious weed *Bromus tectorum* (cheatgrass) was later determined to be a contaminant of the *Elymus trachycaulus* (slender wheatgrass) seed, and so *B. tectorum* plants were removed from pile scars and from the area immediately adjacent to the scars whenever they were encountered. A total of 41 *B. tectorum* plants were removed. Prior to our study, *B. tectorum* was present but infrequent at the Old and Powerline sites and was not encountered at the Aspen site (P. Fornwalt, personal observation).

Data collection

Also in June 2008, we established permanently marked transects which extended from 2 m outside the pile scar on the seeded side, through the scar center, to 2 m outside the scar on the unseeded side (Figure 3). At the Powerline site, slash pile scars were large enough to contain two parallel sampling transects separated by 0.2 m, but scars at the Old and Aspen sites were smaller and only one transect could be established (Figure 3). Six 0.25 m^2 (0.5 m x 0.5 m) subplots were located along each transect (Figure 3). Two subplots per transect (one on the seeded side and one on the unseeded side) were located in the pile scar interior, two were just inside the scar edge, and two were 1 m outside the scar in unburned forest.

Percent plant cover by species was ocularly estimated in each 0.25 m^2 subplot in late July 2008. Nomenclature follows the USDA NRCS Plants Database (2009), though varieties and subspecies were not distinguished. We also used the USDA NRCS Plants Database to determine the growth form, lifespan, and nativity of each species. Native richness per subplot was then calculated by counting the number of native species, while native cover per subplot was calculated by summing the cover all natives. Exotic richness and cover were calculated in the same manner. Voucher specimens are stored at the USDA Forest Service Rocky Mountain Research Station (USFS RMRS) in Fort Collins, Colorado. In each subplot we also estimated the percent cover of abiotic forest floor variables, including, duff, litter, rock, soil, and wood. Measurements were repeated in late July 2009.

Plant available soil nitrogen (N) was assessed using ion exchange resin (IER) bags (Binkley and Matson 1983). In June 2008, resin bags were placed along the sampling transects in areas immediately adjacent to the pile scar interior, scar edge, and outside scar subplots, for a total of six bags per slash pile scar. The bags were inserted in the mineral soil at a depth of 5-10 cm. The bags were constructed of a permeable nylon fabric and filled with mixed bed ion exchange resin that retains inorganic N forms (nitrate (NO_3-N) and ammonium (NH_4-N)) as they percolate through the surface mineral soil layer. To characterize seasonal patterns in nitrogen availability and changes with time since time burning and restoration, bags were removed at the end of the growing season in November and a new set of bags was installed. The second set of bags was removed in May 2009. After collection, bags were stored at 5°C until the resins could be extracted. Resins were extracted with 100 mL of 2 M KCl and analyzed for ammonium and nitrate by Latchat spectrophotometry (Latchat Instruments, Milwaukee, Wisconsin, USA).

Attribute data were collected for each slash pile scar, including scar diameter, slope, aspect, elevation, and UTMs. Percent cover of the forest overstory immediately surrounding each slash pile scar was also assessed using a spherical densiometer. We also noted any additional understory species which were found in and adjacent to the scars but were not sampled in the subplots.

Statistical analyses

All analyses were done using mixed model analysis of variance (ANOVA) in SAS 9.2 (SAS Institute Inc., Cary, North Carolina, USA). Significance for all statistical tests was assessed with an $\alpha = 0.05$. When appropriate, significant independent variables were further examined for pairwise differences between variable levels using least squares means with a Tukey-Kramer adjustment for multiple comparisons. Richness variables were square-root transformed and cover variables were arcsin square-root transformed to approximate ANOVA assumptions of residual normality and homoscedasticity; otherwise, no serious violations of ANOVA assumptions were encountered.

Results

Slash pile burning impacts on soils and plants

Untreated slash pile scars were characterized by a significantly greater amount of bare mineral soil and ash than surrounding unburned areas both one (2008) and two (2009) growing seasons after slash pile burning (Figure 4). Soil and ash cover in interior subplots exceeded 50% in both years, while in edge subplots it exceeded 35%. In contrast, nearly 80% of the surrounding unburned areas were covered by forest floor (i.e., litter, duff, and/or wood), while less than 10% of the ground surface was covered by soil and ash.

The interior of untreated pile scars had significantly more IER-ammonium, IER-nitrate, and total IER-N (i.e., IER-ammonium + IER-nitrate) than areas surrounding the scars for both the 2008 summer and combined 2008/2009 winter and snowmelt seasons (Figure 5). Averaged across the two sampling periods, IER-ammonium was 2.3-fold higher in the interior compared to the exterior of burn scars. IER-nitrate was 2.0-fold higher in burn scar interiors, and comprised a similar amount of the total pool of plant available N inside and outside of the burn scars (e.g., 68 and 71%, respectively). In the zone at the edge of burn scars, average IER-nitrate was similar to levels measured in the scar interiors, whereas IER-ammonium was intermediate between scar interiors and exteriors. Nitrate represents a larger portion of the total IER-N pool in the edge zone compared to scar interior or exteriors for both measurement periods.

IER-N in pile burn scars and surroundings differed between the summer and the combined winter and snowmelt seasons (Figure 5). For scar interiors both forms of IER-N collected during winter/snowmelt were 2.2-fold higher than those collected during summer. In unburned areas surrounding the scars, movement of IER-nitrate was nearly 3-fold higher during winter/snowmelt period than during the summer period. During summer months IER-N in the edge zone was similar to that of the scar interiors whereas edge IER-N was intermediate between scar interior and exterior during winter/snowmelt.

Soil N was significantly higher in one year old pile scars (i.e., Powerline and Aspen sites) than in two year old scars (i.e., Old site; Figure 6). The second year after burning, IER-ammonium declined to 30% of first year levels; total IER-N was half the year 1 level inside burn scars. In second year piles, total IER-N in the scar interior remained slightly elevated, but in scars edges Year 2 total IER-N was equal to that of the surrounding unburned area. The proportion of IER-N comprised of nitrate increased from 60% in one year old scars to 80% in two year old scars. In contrast, IER-nitrate became a lower proportion of total IER-N over time in the edge zone.

Native richness and cover varied significantly with sampling location (i.e., pile scar interior, pile scar edge, and outside pile scar) and sampling year, though richness and cover trends among scar interior, scar edge, and outside scar subplots were consistent among years. Among sampling locations, native richness and cover were considerably greater in scar edges and in the surrounding unburned areas than in the interior of slash pile scars (Figure 7a-d). Native richness and cover were also greater in 2009 than in 2008 (Figures 7a-d).

Similarly, exotic richness and cover varied with both sampling location and year. Exotic richness and cover were greater in 2009 than in 2008, and were generally higher outside of slash pile scars than inside the scars (Figures 7a-d).

Effects and effectiveness of slash pile scar restoration treatments

Slash pile scar restoration treatments significantly altered plant-available N in the pile interior and edge zones within months of applying the treatments (Figure 8a). Averaged across the summer and winter/snowmelt seasons, mulching reduced IER-ammonium by more than 60% in both the scar interior and edge zones (Figures 8a, b). In contrast, scarification doubled IER-nitrate and increased total IER-N 1.7-fold relative to untreated controls in the months after treatment installation. The proportion of nitrate of total IER-N was higher in scarified burn scars (82%) than in either untreated scars (68%) or surrounding unburned areas (73%). Scarification had no effect on IER ammonium and effects on soil N were limited to scar interiors.

The influence of restoration treatments on burn scar soil N varied seasonally (Figures 8a, b). Relative to the amount of total IER-N beneath mulch during the summer measurement period, total IER-N decreased by about half during the winter/snowmelt season, whereas in the interior of untreated burn scars and in the area surrounding the scars, the N collected on exchange resins increased during the winter/snowmelt period. Likewise, mulch reduced IER ammonium and nitrate by 87 and 75% in scar interiors and by 64 and 71% in scar edges, respectively. These levels are depressed well below what was measured in unburned areas. In contrast, soil N in scarified burn scars increased by about 50% during the 2008/2009 winter/snowmelt season relative to the summer 2008 season, and was roughly equal to levels measured in untreated burn scars.

Plant surveys conducted in July 2008, one month after treatment installation, show that the surface and seeding treatments had little to no immediate impact on native richness and cover or on exotic richness/cover.

However, surveys conducted in July 2009, thirteen months after treatment installation, indicate that native richness and cover varied considerably with regard to surface treatments, seeding treatments, and subplot location (Table 3; Figures 9a, b). In pile scar interiors, both surface and seeding treatments impacted native richness and cover — richness and cover were greater in mulched and scarified pile scars than in control scars, and they were also greater in the seeded halves of scars than in the unseeded halves. The impacts of surface and seeding treatments were considerably less pronounced at the pile scar edges. Surface treatments had no impact on either native richness or cover, while seeding increased native richness but not native cover.

2009 exotic richness and cover appeared to be less responsive to the surface and seeding treatments (Table 3; Figures 10a, b). In the interior of pile scars, exotic richness was greater in mulched areas than in other surface treatment x seed treatment combinations. Exotic cover in interior subplots was lower in the seeded halves of pile scars than in the unseeded halves, though surface treatments had no additional effect. In scar edges, we found no impact of surface or seeding treatments on either exotic richness or cover.

Establishment success of seeded species

We did not observe any seeded grass establishment at the time of sampling in 2008, one month after treatments were installed. However in 2009, thirteen months after treatment, the cover of seeded species in seeded slash pile scar halves averaged 9.5%, most of which was due to *Elymus trachycaulus* (Figures 11, 12).

The effect of the mulching, scarifying, and control treatments on *E. trachycaulus* cover varied with sampling location (Figure 12a) — though *E. trachycaulus* cover differed among treatments in the interior of slash pile scars ($p < 0.001$), with cover greater in mulched than in scarified and control scars, cover did not differ among treatments at the scar edge. In contrast, *Elymus elymoides* cover varied among the three surface treatments in both interior and edge subplots (Figure 12b). In both locations, *E. elymoides* cover was greatest in mulched scars and lowest in control scars. *Muhlenbergia montana* cover did not vary among the three surface treatments in either interior or edge subplots (Figure 12c).

Lower montane forests: Bald Mountain, Gold Hill, and Walker Ranch

Methods

Study sites

Three sites were established in 2009 on BCPOS land. One site is located at Bald Mountain Scenic Area, one site is near the town of Gold Hill, and one site is at Walker Ranch (Table 4; Figure 13). These sites are part of a larger study of 20 sites distributed throughout Larimer and Boulder Counties, with the additional 17 sites located on USFS land (Figure 13). The study site information that follows describes only the BCPOS sites; however the restoration treatments, data collection methods, and analytical approach described below will be applicable to all 20 sites.

Soils at the three BCPOS sites are gravelly sandy loams weathered from granite (http://websoilsurvey.nrcs.usda.gov). Annual precipitation in the centrally located mountain town of Sugarloaf averages 39 cm, most of which falls during the spring and summer (http://www.wrcc.dri.edu). There is typically not a persistent winter snowpack at any of the three sites. The coldest temperatures occur in February, when daytime highs average 6.2°C and daytime lows average -6.3°C; July is the warmest month, with maximum daytime temperatures averaging 31.2°C (http://www.wrcc.dri.edu).

The Bald Mountain site is on flat to gently sloping southwest-facing terrain at an elevation of ~2160 m (Table 4). Bald Mountain was thinned in 2008, and the thinned slash was immediately piled and burned in spring 2009. The residual overstory is sparse (35 trees ha^{-1}) and is dominated by large *Pinus ponderosa* (ponderosa pine) trees (Table 4). There is a vigorous understory dominated by native grasses and forbs such as *Artemisia ludoviciana* (white sagebrush), *Elymus elymoides* (squirreltail), *Heterotheca villosa* (hairy false goldenaster), and *Koeleria macrantha* (prairie Junegrass). Exotic species are common and include *Bromus inermis* (smooth brome), *Bromus tectorum* (cheatgrass), *Cirsium arvense* (Canada thistle), *Tragopogon dubius* (yellow salsify), and *Verbascum thapsus* (common mullein). The slash piles at Bald Mountain appear to have burned intensely, as the scars all have a considerable amount of bare soil and ash, with little charcoal, woody debris, and vegetation remaining. Pile scars have an average diameter of 4.0 m.

The site at Gold Hill is located on flat, rocky terrain at ~2580 m elevation (Table 4). Gold Hill was thinned and piled in 2008 and the piles were burned in spring 2009. The thinned overstory has a density of 220 trees ha^{-1} and is dominated by *P. ponderosa*, with *Pseudotsuga menziesii* (Douglas-fir) occuring intermittently. The understory community contains native species such as *Achillea millefolium* (common yarrow), *Arctostaphylos uva-ursi* (kinnikinnick), *E. elymoides*, and *Juniperus communis* (common juniper). *B. tectorum* was the only exotic species noted. Slash piles at this site burned with moderate to high severity, with some charcoal and woody debris remaining in the scars. The average diameter of pile scars at Gold Hill is 2.6 m.

The slash pile scars at Walker Ranch are on a north-facing slope at ~2210 m elevation (Table 4). Walker Ranch was thinned to a density of 210 trees ha^{-1} in 2007; the slash was immediately piled and then burned in spring 2009. *P. menziesii* is the dominant overstory species, with *P. ponderosa* and *Juniperus scopulorum* (Rocky Mountain juniper) also occurring. Common native understory plants include *A. ludoviciana*, *E. elymoides*, and *Solidago* (goldenrod) sp. Exotic species at the site include *B. inermis*, *B. tectorum*, *C. arvense*, *T. dubius*, and *V. thapsus*. Slash piles at Walker burned with near complete consumption, and scars are dominated by bare soil and ash with little to no charcoal, woody debris, or vegetation remaining. Scars average 3.8 m in diameter.

Ten slash pile scars at each site were selected for use in this study. Scars were chosen to be as consistent as possible at a site in terms of size, shape, burn severity, slope, aspect, and the amount and composition of overstory and understory vegetation within and surrounding scars.

Restoration treatments

We implemented eight slash pile scar restoration treatments at the sites, with one scar per site receiving each treatment. Treatments were randomly assigned to scars, and were installed in late October and early November of 2009. Treatments included:

– Scarification	– Scarification + seed application
– Slash mulch application	– Slash mulch + seed application
– Mulch application	– Mulch + seed application
– Untreated control	– Control + seed application.

Scarification was done by raking the slash pile scars by hand with a McLeod to a depth of 10 cm (Figure 14a). The slash mulch treatment was implemented by placing tree branches and boles <8 cm in diameter on top of the scars (Figure 14b). All slash for the mulch was gathered from the surrounding area and was piled in random directions until branch cover was ~50%. Mulched pile scars were covered 6 cm deep with local chipped woody material (Figure 14c). Scars which received a seed treatment were hyperseeded with a diverse mixture of early-, mid-, and late-seral native species at a rate of 2700 seeds m^{-2} (Table 5). The species used in the seeding treatment were chosen based on several criteria, including ecological appropriateness, our observations in the sites or in similar habitats in the region, and the advice of local experts (Claire DeLeo, BCPOS; Mark Paschke, Colorado State University; Steve Popovich, USFS Arapaho-Roosevelt National Forests). All seed was either locally collected or purchased from reputable sources. When seed was purchased, we always bought wild-types rather than improved varieties whenever possible, and we attempted to purchase lots that were collected in areas as close in ecological amplitude as possible to our sites. All seed lots used were tested for purity at the Colorado Seed Laboratory, and any lots that contained noxious species were discarded. Seed was spread by hand in the pile scars to ensure even and complete coverage and then gently tamped into the soil with a Mcleod. Where seeded piles were also scarified, slash mulched, or mulched, the seed was applied prior to slash mulching and mulching but after scarification.

Data collection

Slash pile scar attribute data were collected for each pile scar in summer 2009, including pile length, width, surface characteristics, UTM coordinates, and elevation. Informal plant surveys of the species growing in the pile interior, pile edge, and surrounding unburned area were also made at this time. Several photographs were taken of each scar and the scar edges were marked on north-south and east-west transects with metal stakes. Overstory stand basal area and stand density were assessed at each site by establishing two to three randomly located 0.1 ha plots per site; in each 0.1 ha plot, we recorded the diameter, species, and live/dead status of each tree >1.37 m tall.

In late summer 2010, we will measure plant biomass and cover by species in nine 0.25 m^2 subplots per slash pile scar. Three subplots will be randomly located in the scar center, three will be randomly located in the scar edge, and three will be randomly located 2 m outside the scar. Cover will be ocularly estimated to the nearest 1% for each species in a subplot, while biomass will be estimated by clipping all live material for each species in a subplot at ground level and placing the material in paper bags. Clipped plant material will be oven dried for a minimum of 24 hours and weighed. This sampling procedure will be repeated in late summer 2011. Care will be taken to avoid placing subplot frames in areas that were obviously clipped in the previous year.

In November 2009, a bulb planter was used to extract soil samples from three randomly located center, edge, and outside subplots of the two remaining untreated pile scars at each site. Soil samples will be laid out in a shallow container in the greenhouse in early 2010. The samples will be kept at an ideal temperature for germination and watered daily. Samples will be monitored once a week for plant emergence. All germinated plants will be identified, documented, and then removed from the growing container to allow additional seeds to germinate.

At each site, three ion exchange resin bags were installed in the scarified, slash mulched, mulched, and control scars to assess the effects of these treatments on the amount of plant-available nitrogen. Bags were installed in November 2009 and were placed along north-south transects that ran from the pile center to the unburned forest outside the pile. One bag was placed in the pile center, one bag was placed just inside the pile edge, and one was placed 2 m outside the pile. The bags were inserted in the mineral soil at a depth of 5-10 cm. These bags will be removed in early spring 2010 and analyzed to estimate dormant season nitrogen availability. New sets of bags will be installed in the spring at the beginning of the growing season in 2010, fall 2010, and spring 2011.

Statistical analyses

Plant, seedbank, and soils data from all 17 USFS and BCPOS sites will be analyzed using mixed model analysis of variance (ANOVA). Repeated measures will be used when comparing variables through time (2010-2011).

Results

There are no results to report at this time.

Discussion

Slash pile burning impacts on soils and plants

Slash pile burning is a widespread fuels reduction treatment because of its practicality and cost-effectiveness. However, soil temperatures due to slash pile burning have been shown to exceed 300°C during pile burning and to remain above 100°C for days following ignition (Massman et al. 2008). Furthermore, the pulse of heat measured beneath pile burns can extend to depths greater than 1 m. This extreme fire intensity can alter physical, chemical and biological soil properties and have prolonged consequences on plant community composition and productivity (DeBano et al. 1998; Ice et al. 2004).

High intensity fire due to slash burning typically consumes all of the organic forest floor and all living plant cover, exposing the mineral soil surface (Arocenaa and Opio 2003; Covington et al. 1991). Results from our study in upper montane forests at Reynolds Ranch also indicate that slash pile burning greatly diminished the amount of forest floor material (i.e., litter, duff, and wood), particularly in the interior of the slash pile scars (Figure 4). Relative to unburned areas just outside the pile scars, where more than 80% of the ground surface was covered with organic forest floor material, the interior of slash pile scars were dominated by bare soil, even after two years of recovery. Indeed, the bare soil exposed during slash pile burning may persist for several years following burning. In Missouri oak savanna where surface fire consumed downed tree boles and concentrated heavy fuels, soils remain devoid of vegetation for more than three years (Rebertus and Burns 1997), while slash piles burned in pinyon-juniper woodlands of Arizona remained unvegetated for more than five years (Covington et al. 1991).

The combustion of woody slash material has been found to cause sharp, immediate increases in soil N availability and soil ammonium in many North American conifer forests (Covington et al. 1991; Korb et al. 2004; Wan et al. 2001). Our results are consistent with these findings (Figure 5). 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 (Fisher and Binkley 2000; Certini 2005). These soil N pools usually return to prefire levels 2 to 5 years after burning as plant and microbial N uptake drain these labile and scarce soil resources (Covington et al. 1991; Esquilín et al. 2007). We found that the total amount of N was lower two years after burning than in the first postfire year, but the proportion of nitrate was greater (Figure 6).

Exotic plants often establish readily after slash pile burning due to elevated soil N and bare soil availability (Haskins and Gehring 2004; Korb et al. 2004; Wolfson et al. 2005). While our data show that the levels of exotic richness and cover inside slash pile scars did not increase relative to the levels found in the unburned surrounding areas, despite increases in soil N and bare soil, a trend of increasing exotic richness and cover within scars was apparent over time (Figure 7). The fact that many of the exotic species identified in our plant surveys are classified as noxious weeds by the state of Colorado further suggests that exotics may continue to spread in the scars as time passes. Indeed, the noxious weeds *Cirsium arvense* (Canada thistle) and *Verbascum thapsus* (common mullein) were the two most abundant exotics at our sites. Across all subplots and years, the combined cover of these two species averaged more than 2% — which represents nearly 90% of the average total exotic cover recorded in the subplots. *C. arvense* and *V. thapsus* are well-known for their ability to aggressively invade disturbed areas and further monitoring is recommended (Crawford et al. 2001; Fornwalt et al. in press; Floyd et al. 2006).

Native plant species in upper montane forests are well-adapted to high-severity fire (Anderson and Romme 1991; Stickney and Campbell 2000; Turner et al. 1999), yet the extreme soil temperatures that occur during slash pile burning at the pile's center are considerably greater than those created by even the most severe wildfire (Massman et al. 2008). These extreme temperatures greatly diminished native richness and cover in the interior of the pile scars (Figure 7 a-d). Those species that did manage to establish in the interior of the scars likely did so from surviving seeds in the soil seedbank, such as the ruderal forbs *Chenopodium leptophyllum*, *Corydalis aurea*, and *Phacelia heterophylla*; we observed almost no native species establishing from surviving belowground roots and rhizomes in the center of the pile scars. In contrast, lower fire severity at the scar edge allowed for the establishment of native plants from both surviving belowground organs and from the soil seedbank, and as a result, native richness and cover at the scar edge were comparable to levels found outside the scars (Figures 7 a-d).

Effects and effectiveness of slash pile scar restoration treatments

Surface application of mulched wood residue is becoming an increasingly common method for disposing of hazard fuels throughout western forest ecosystems, but the consequences of this activity are poorly understood. Our study found that a 4-6 cm layer of wood mulch applied to the surface of pile scars helped to reverse the increase in soil N availability created by pile burning (Figure 8). The mulch depressed ammonium in burn scars during the months following treatment installation and reduced both nitrate and ammonium to pre-burn levels during the winter/snowmelt period. When applied to unburned forest soils the effects of wood mulch on soil N availability are mixed. Mechanical fuels reduction activities that added 3-5 cm of wood mulch to ponderosa and lodgepole ecosystems across Colorado had only marginal effects on stand-level soil N availability (Battaglia et al. in review). However, where mulch depth exceeded 7.5 cm, mulching reduced soil N availability (Rhoades et al. in preparation). Similarly, a 10 cm application of wood mulch reduced soil N by 60% in a Colorado lodgepole pine forest (Binkley et al. 2003). Wood mulch has been shown to reduce soil N by providing soil microbes a source of readily-available carbon (C) that stimulates their growth and uptake of soil N (Eschen et al. 2007; Zink and Allen 1998). A reduction in N may persist for several months to several years following the addition of mulch or other C sources (Baer et al. 2003; Morgan 1997; Reever-Morgan and Seastedt 1999).

Carbon additions that depress soil N can favor the establishment of native plants over nitrogen-loving invasive species. For example, Blumenthal et al. (2003) found that C addition facilitated the growth of native prairie species and suppressed exotics in a Minnesota field experiment. Similarly, a study by Zink and Allen (1998) revealed that C addition allowed a dominant native perennial shrub species to outcompete exotic annuals in a disturbed California sage scrub habitat. Our findings also indicate that wood mulch favored native plant establishment at the Reynolds Ranch sites (Figures 9a, b), though it is unclear whether the native species were responding to lower N availability or to the higher soil moisture that was found under the mulch layer (Binkley et al. 2003; Rhoades et al. in preparation; P. Fornwalt personal observation). Because most of the native species growing in mulched pile scars were ruderal species, and because exotic richness also responded favorably to the mulching treatment (Figures 10 a, b), we suspect that the latter is the more likely scenario.

Surface mulch application is likely to have additional benefits for ecosystem health. Like the transplant of forest floor layers to pile burn scars (Korb et al. 2004), application of woody mulch may create conditions that improve colonization of mycorrhizal symbionts. Soil cover and surface roughness created by the mulch layer may also reduce rain splash, sheet erosion, and surface sealing, all of which are common to severely-burned forest soils (Pannkuk and Robichaud 2003; Larsen et al. 2009).

Scarification is widely used by forest managers to expose a mineral seedbed, aid tree seedling establishment and reduce competing vegetation (Johansson et al. 2005), but little is known the utility of this treatment for restoring soils degraded by pile burning. The hand scarification treatment we conducted was designed to disrupt surface sealing and the water repellant soil layers, and to mix nutrients contained within the ash layer into the mineral soil (Larsen et al. 2009). Scarification increased soil N availability in the months following treatment implementation, and the N condition remained comparable or greater than untreated pile burn scar soils throughout our study period. Research in Colorado ponderosa pine forests has found that scarification alters soil C and N pools and microbial biomass more than wildfire and that the effect of scarification can persist for 25 years (Esquilin et al. 2008).

As with mulching, our results show that scarifying pile scars favored native richness and cover in pile scar interiors (Figures 9a, b), probably due to improved soil-water relations and to increased N availability in scarified pile scars. Surprisingly, scarification did not stimulate exotics (Figures 10a, b), though we are unsure as to the mechanism or mechanisms underlying this response. Unfortunately, further insight into the effects of postfire scarification on native and exotic species is lacking, as comparable studies are not available in the literature.

We found that seeding native species into slash pile scars directly increased native richness in both the scar interior and the scar edge, and also increased native cover and decreased exotic cover in scar interiors (Figures 9a,b; 10 a, b). This finding is consistent with Korb et al. (2004), who tested the effectiveness of a diverse native seed mix at restoring native plant communities and reducing exotic abundance in Arizona slash pile scars. Furthermore, in scar interiors the combination of mulching plus seeding generated the highest levels of native richness and cover (Figures 9a, b). Native richness and cover values observed in mulched and seeded interior subplots were nearly two times greater than that observed in the control scars (Figures 9a, b), and were on par with that observed in unburned areas outside the pile scars (Figures 7a-d).

Establishment success of seeded species

Of the three seeded grass species used in the treatments, *Elymus trachycaulus* was by far the most successful in terms of cover (Figure 12a). Peterson et al. (2004) also found that *E. trachycaulus* was a superior species for revegetating road cuts in Bryce Canyon National Park. *E. trachycaulus* has been found to be competitive with exotic species (Lulow 2006; Lym and Tober 1997).

E. trachycaulus is short-lived and populations often decline after a few years (Claire DeLeo, personal communication; USDA NRCS 2009). Furthermore, commercial varieties of E.

trachycaulus, such as 'San Luis' used here, often do not perform as well as their indigenous counterparts, probably because they are not as adapted to the local growing environment (Peterson et al. 2004). Therefore, it is generally recommended that seed mixes containing *E. trachycaulus* also contain slower-growing, longer-lived species (USDA NRCS 2009). Our mix also contained locally collected seeds of *E. elymoides* and *Muhlenbergia montana*, which germinated readily in the slash pile scars, though plants were small (Figure 12 b, c). It is our hope that these species will continue to grow and provide cover if and when *E. trachycaulus* begins to wane.

Conclusions and management recommendations

Results from upper montane forests indicate that slash pile burning diminished understory plant richness and cover in upper montane forests of Boulder County over the short term (1-2 growing seasons after burning). This effect was most pronounced in the interior of pile scars, where the fire burned hottest. The decrease in richness and cover occurred despite the fact that the burning greatly increased the amount of plant-available nitrogen in the scars. Our results also indicate that restoration treatments further impacted plants and soils in slash pile scars. Relative to untreated pile scars, mulching decreased soil nitrogen and increased native richness and cover in the interior of scars, but also increased exotic richness. In contrast, scarification increased soil nitrogen and native richness and cover in scar interiors, but had no impact on exotics. Seeding native species into slash pile scars directly increased native richness and cover and decreased exotic cover in scar interiors. Furthermore, in scar interiors the combination of mulching plus seeding generated native richness and cover values that were nearly two times greater than those observed in the control scars, and were on par with values observed in unburned areas outside the pile scars. Of the three perennial grass species used in our seeding treatments, *Elymus trachycaulus* (slender wheatgrass) was by far the most successful, though this species is short-lived and populations may decline after a few years. It is our hope that *E. elymoides* and *Muhlenbergia montana*, which were also included in seeding treatments and germinated readily in the scars, will continue to grow and provide cover if and when *E. trachycaulus* begins to wane.

These results suggest that mulching and seeding slash pile scars in upper montane forests of Colorado may help managers restore prefire soil properties, encourage native plant community development, and possibly reduce exotic invasion. The applicability of our findings to lower montane forests remains unknown at this point.

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Table 1. Site and study design attributes of the Powerline, Old, and Aspen sites. Canopy cover is the cover of the area after thinning.

	Powerline	**Old**	**Aspen**
Site attributes			
Overstory dominants	*Pinus contorta*	*Pinus contorta*	*Populus tremuloides, Pinus contorta*
Mean canopy cover (%)	11.6	20.6	15.1
Mean elevation (m)	2637	2641	2608
Terrain	Flat to rolling	Flat	Flat
Year thinned	Summer 2005	Summer 2005	Summer 2006
Year piles burned	Winter 2007-2008	Winter 2006-2007	Spring 2008
Study design attributes			
No. of blocks	5	3	6
No. of transects per pile	2	1	1
Mean pile diameter (m)	6.4	4.1	3.6
Mean pile area (m^2)	32.2	13.2	10.2

Table 2. The three grass species seeded at the Powerline, Old, and Aspen sites, and the proportion of each species in the seed mix.

Species	**Seed origin**	**% of Mix**
Elymus elymoides, squirreltail	Collected on BCPOS properties (Meyers, Walker Ranch)	14
Elymus trachycaulus ‘San Luis,’ ‘San Luis’ slender wheatgrass	Purchased from Arkansas Valley Seed; grown out in North Dakota	36
Muhlenbergia montana, mountain muhly	Collected on BCPOS properties (Caribou, Mud Lake, Walker Ranch)	50

Table 3. Understory species found in the subplots at the Powerline, Old, and Aspen sites.

Species	**Nativity**	**2008**	**2009**
Short-lived forbs			
Bahia dissecta, ragleaf bahia	Native		X
Chenopodium sp., goosefoot	Variable		X
Chenopodium berlandieri, pitseed goosefoot	Native		X
Chenopodium capitatum, blite goosefoot	Native		X
Chenopodium fremontii, Fremont’s goosefoot	Native	X	X
Chenopodium leptophyllum, narrowleaf goosefoot	Native	X	X
Chenopodium overi, Over’s goosefoot	Native		X
Conium maculatum, poison hemlock	Exotic		X
Conyza canadensis, Canadian horseweed	Native	X	X
Corydalis aurea, scrambled eggs	Native	X	X
Descurainia sophia, herb sophia	Exotic		X
Dracocephalum parviflorum, American dragonhead	Native	X	X
Epilobium brachycarpum, tall annual willowherb	Native		X
Erysimum capitatum, sanddune wallflower	Native		X
Euphorbia sp., spurge	Variable		X
Gnaphalium uliginosum, marsh cudweed	Exotic		X
Lactuca serriola, prickly lettuce	Exotic	X	X
Phacelia heterophylla, varileaf phacelia	Native	X	X
Pseudognaphalium viscosum, winged cudweed	Native	X	
Sonchus asper, spiny sowthistle	Exotic		X
Tragopogon dubius, yellow salsify	Exotic		X
Trifolium pratense, red clover	Exotic	X	X
Verbascum thapsus, common mullein	Exotic	X	X
Long-lived forbs			
Achillea millefolium, common yarrow	Native	X	X
Allium geyeri, Geyer’s onion	Native		X
Anemone canadensis, Canadian anemone	Native	X	
Antennaria parvifolia, small-leaf pussytoes	Native	X	X
Arnica chamissonis, Chamisso arnica	Native	X	X
Artemisia ludoviciana, white sagebrush	Native	X	X
Astragalus alpinus, alpine milkvetch	Native	X	X
Astragalus miser, timber milkvetch	Native	X	X
Campanula rotundifolia, bluebell bellflower	Native	X	X

Species	Nativity	2008	2009
Carduus nutans, nodding plumeless thistle	Exotic		X
Chamerion angustifolium, fireweed	Native	X	X
Cirsium sp., thistle	Variable	X	X
Cirsium arvense, Canada thistle	Exotic	X	X
Cirsium centaureae, fringed thistle	Native		X
Epilobium ciliatum, fringed willowherb	Native	X	X
Erigeron compositus, cutleaf daisy	Native	X	X
Erigeron speciosus, aspen fleabane	Native	X	X
Fragaria sp., strawberry	Native	X	X
Galium boreale, northern bedstraw	Native	X	X
Geranium caespitosum, pineywoods geranium	Native	X	X
Geranium richardsonii, Richardson’s geranium	Native		X
Heuchera parviflora, littleflower alumroot	Native		X
Hieracium albiflorum, white hawkweed	Native		X
Lupinus argenteus, silvery lupine	Native	X	X
Maianthemum stellatum, starry false lily of the valley	Native		X
Mertensia lanceolata, prairie bluebells	Native	X	
Oreochrysum parryi, Parry’s goldenrod	Native	X	X
Packera fendleri, Fendler’s ragwort	Native	X	X
Penstemon virens, Front Range beardtongue	Native	X	X
Potentilla fissa, bigflower cinquefoil	Native		X
Potentilla pulcherrima, beautiful cinquefoil	Native	X	X
Pseudocymopterus montanus, alpine false springparsley	Native	X	X
Rumex acetosella, common sheep sorrel	Exotic		X
Sedum lanceolatum, spearleaf stonecrop	Native	X	X
Senecio eremophilus, desert ragwort	Native		X
Solidago simplex, Mt. Albert goldenrod	Native	X	X
Symphyotrichum sp., aster	Native	X	
Taraxacum officinale, common dandelion	Exotic	X	X
Thalictrum fendleri, Fendler’s meadow-rue	Native	X	X
Thermopsis divaricarpa, spreadfruit goldenbanner	Native	X	X
Trifolium repens, white clover	Exotic	X	X
Zigadenus elegans, mountain deathcamus	Native		X
Graminoids			
Agrostis scabra, rough bentgrass	Native	X	X
Bromus tectorum, cheatgrass	Exotic		X

Species	**Nativity**	**2008**	**2009**
Calamagrostis purpurascens, purple reedgrass	Native	X	X
Carex sp., sedge	Native	X	X
Elymus elymoides, squirreltail	Native		X
Elymus trachycaulus, slender wheatgrass	Native		X
Festuca saximontana, Rocky Mountain fescue	Native		X
Hordeum jubatum, foxtail barley	Native		X
Muhlenbergia montana, mountain muhly	Native		X
Phleum pratense, timothy	Exotic	X	X
Poa sp., bluegrass	Variable	X	X
Poa compressa, Canada bluegrass	Exotic		X
Poa pratensis, Kentucky bluegrass	Exotic	X	X
Woody plants			
Arctostaphylos uva-ursi, kinnikinnick	Native	X	X
Juniperus communis, common juniper	Native	X	X
Pinus contorta, lodgepole pine	Native	X	X
Pinus flexilis, limber pine	Native	X	
Populus tremuloides, quaking aspen	Native	X	X
Pyrola chlorantha, greenflowered wintergreen	Native	X	X
Ribes cereum, wax currant	Native		X
Rosa sp., rose	Native	X	X
Rubus idaeus, American red raspberry	Native	X	X
Salix sp., willow	Native	X	X

Table 4. Site and pile attributes for the Bald Mountain, Gold Hill, and Walker Ranch sites.

	Bald Mountain	**Gold Hill**	**Walker Ranch**
Site attributes			
Overstory dominants	*Pinus ponderosa*	*Pinus ponderosa, Pseudotsuga menziesii*	*Pseudotsuga menziesii, Pinus ponderosa, Juniperus scopulorum*
Mean stand density (trees ha^{-1})	35	220	210
Mean stand basal area (m^{2} ha^{-1})	2.8	11.6	6.2
Mean elevation (m)	2160	2580	2210
Terrain	Flat to gently sloping	Flat	North-facing slope
Year thinned	2008	2008	2007
Year piles burned	Spring 2009	Spring 2009	Spring 2009
Pile attributes			
Mean pile diameter (m)	4.0	2.6	3.8
Mean pile area (m^{2})	12.3	5.4	11.2
Pile burn severity	Hot – near complete consumption	Moderate – charcoal and woody debris remain	Hot – near complete consumption

Table 5. Species seeded at the Walker Ranch, Bald Mountain, and Gold Hill sites, and the proportion of each species in the seed mix.

Species	**Life History**[a]	**Seed origin**	**% of Mix**
Allium cernuum, nodding onion	P forb	Purchased from Sunmark Seed	4
Artemisia frigida, prairie sagewort	P forb	Purchased from Southwest Seed; collected in 2008 at Heil Valley Ranch, Boulder County, 1900 m	4
Artemisia ludoviciana, white sagebrush	P forb	Purchased from Western Native Seed	4
Bouteloua gracilis, blue grama	P grass	Purchased from Southwest Seed; grown out in CO	3
Campanula rotundifolia, bluebell bellflower	P forb	Purchased from Sunmark Seed	3
Chamerion angustifolium, fireweed	P forb	Purchased from Granite Seed; grown out in UT	6
Chenopodium leptophyllum, narrowleaf goosefoot	A forb	Collected in 2009 at Reynolds Ranch, Boulder County, 2600 m	13
Chenopodium fremontii, Fremont's goosefoot	A forb	Collected in 2009 at Reynolds Ranch, Boulder County, 2600 m	6
Danthonia spicata, poverty oatgrass	P grass	Collected in 2008 at Heil Valley Ranch, Boulder County, 1900 m	2
Elymus lanceolatus ssp. *lanceolatus* 'Critana,' 'Critana' thickspike wheatgrass	P grass	Purchased from Southwest Seed; grown out in WA	2
Elymus trachycaulus 'San Luis,' 'San Luis' slender wheatgrass	P grass	Purchased from Southwest Seed; grown out in Canada	2
Elymus elymoides, squirreltail	P grass	Purchased from Granite Seed; grown out in WA	2
Eriogonum umbellatum, sulphur-flower buckwheat	P forb	Collected in 2009 at Walker Ranch, Boulder County, 2200 m	4
Festuca arizonica 'Redondo,' 'Redondo' Arizona fescue	P grass	Purchased from Western Native Seed; grown out in WY	3
Grindelia squarrosa, curlycup gumweed	A/P forb	Purchased from From the Forest; grown out in ID	3
Harbouria trachypleura, whiskbroom parsley	P forb	Collected in 2009 at Heil Valley Ranch, Boulder County, 1900 m	2

Species	**Life History**[a]	**Seed origin**	**% of Mix**
Heterotheca villosa, hairy false goldenaster	P forb	Collected in 2009 at Bald Mountain, Boulder County, 2100 m	4
Koeleria macrantha, prairie Junegrass	P grass	Collected in 2009 at Walker Ranch, Boulder County, 2200 m	3
Liatris punctata, dotted blazing star	P forb	Purchased from Western Native Seed; Collected in 2007 at Rabbit Mountain, Boulder County, 1700 m	3
Lupinus argenteus ssp. *rubricaulis*, silvery lupine	P forb	Purchased from Granite Seed; grown out in NV	3
Muhlenbergia montana, mountain muhly	P grass	Collected in 2008 at Walker Ranch, Boulder County, 2200 m	2
Pascopyrum smithii ‘Arriba,’ ‘Arriba’ western wheatgrass	P grass	Purchased from Southwest Seed; grown out in WY	1
Penstemon virens, Front Range beardtongue	P forb	Collected in 2009 at Walker Ranch, Boulder County, 2200 m	4
Phacelia heterophylla, varileaf phacelia	B/P forb	Collected in 2009 at Reynolds Ranch, Boulder County, 2600 m; collected in 2009 along 9J Road, Douglas County, 2500 m	1
Poa fendleriana, muttongrass	P grass	Purchased from Granite Seed; grown out in CO	2
Potentilla fissa, bigflower cinquefoil	P forb	Collected by BOCO in 2009 at Walker Ranch, Boulder County, 2200 m	2
Potentilla hippiana, woolly cinquefoil	P forb	Purchased from Western Native Seed	4
Ribes cereum, wax currant	P shrub	Purchased from Granite Seed; grown out in UT	3
Rosa woodsii, Wood’s rose	P shrub	Purchased from Western Native Seed	4
Solidago simplex, Mt. Albert goldenrod	P forb	Collected in 2009 at Reynolds Ranch, Boulder County, 2600 m	1
Symphyotrichum porteri, smooth white aster	P forb	Collected in 2009 at Manitou Experimental Forest, Douglas County, 2400 m	1
Thermopsis divaricarpa, spreadfruit goldenbanner	P forb	Collected in 2009 along Forest Service Road 171, Larimer County, 2700 m	1

[a] A = annual; B = biennial; P = perennial.

Figure 1. Location of the Powerline, Old and Aspen sites at Reynolds Ranch, Boulder County, Colorado.

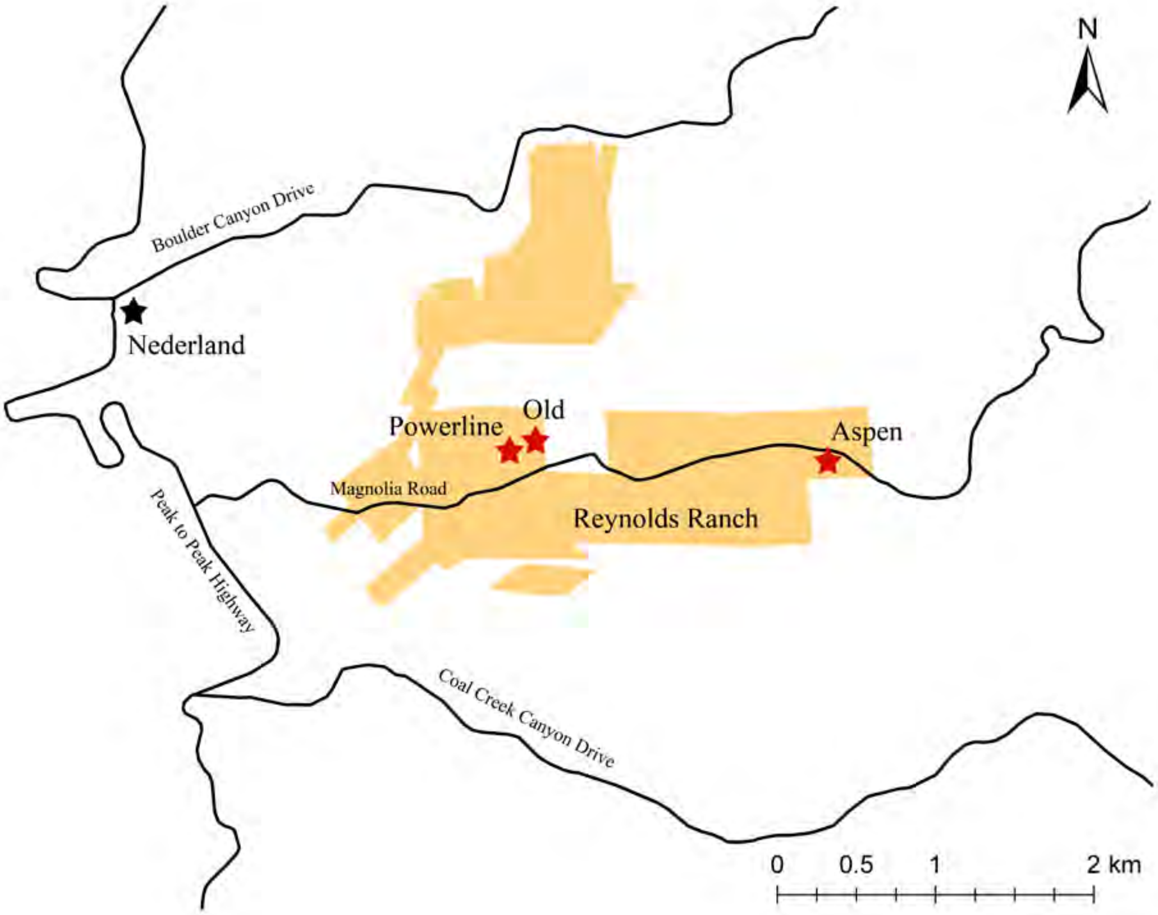


Figure 2. Surface treatments at Reynolds Ranch included untreated control, scarify, and mulch. Half of each pile also received a seeding treatment.

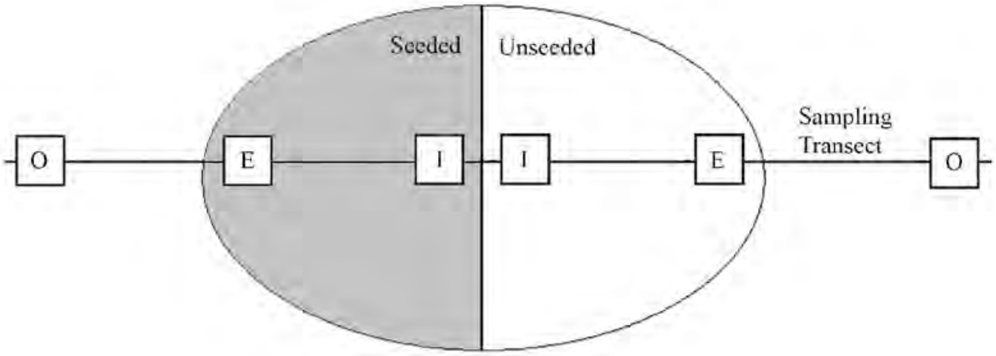
(a). Control slash pile scar at the Old site

(b). Scarifying a pile scar at the Old site

(c). Mulch applied to a pile scar at the Old site

Figure 3. Slash pile scar sampling methods at the Aspen and Old sites, and the Powerline site at Reynolds Ranch. Understory vegetation and abiotic sampling were conducted in subplots distributed along transects which extended from 2.5 m outside the pile on the seeded side to 2 m outside the pile on the unseeded side. Soil sampling for plant available nitrogen was conducted adjacent to the subplots. O = outside pile (unburned) subplots, E = pile scar edge subplots, and I = pile scar interior subplots.

a). Aspen and Old sites



b). Powerline site

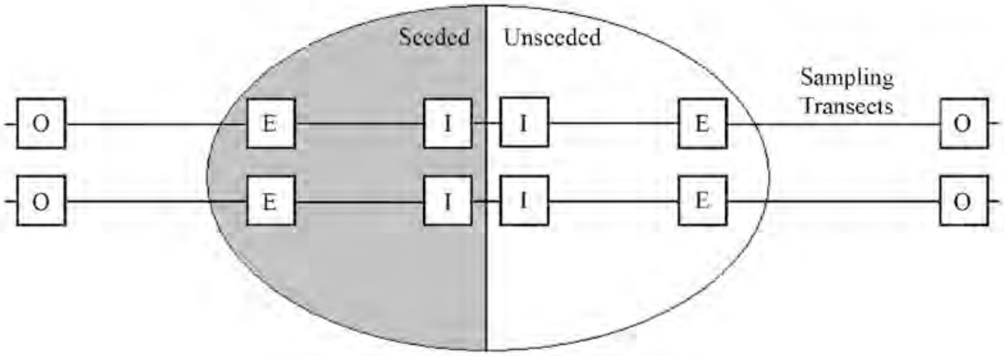


Figure 4. Changes in ground cover composition after slash pile burning. Data are means and standard errors for the 14 untreated control pile scars (unseeded side only). The forest floor is composed of litter, duff and wood. Other includes rock, moss and lichen. The sum of the variables may exceed 100% due to overlap among the elements.

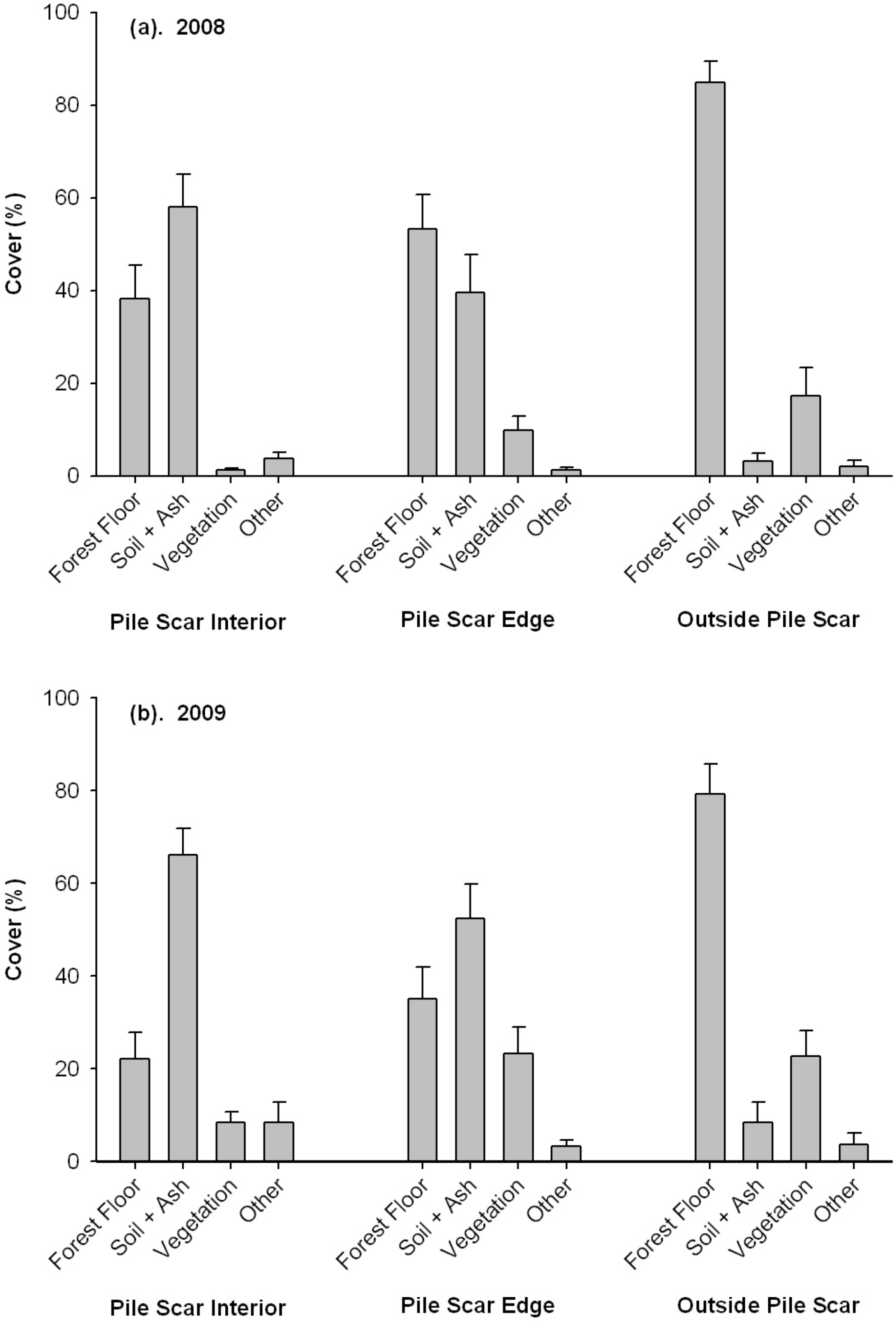


Figure 5. Ion exchange resin nitrogen at the three Reynolds Ranch sites for the summer growing season and for the combined winter and snowmelt seasons. Data are means and standard errors for the 14 untreated control pile scars.

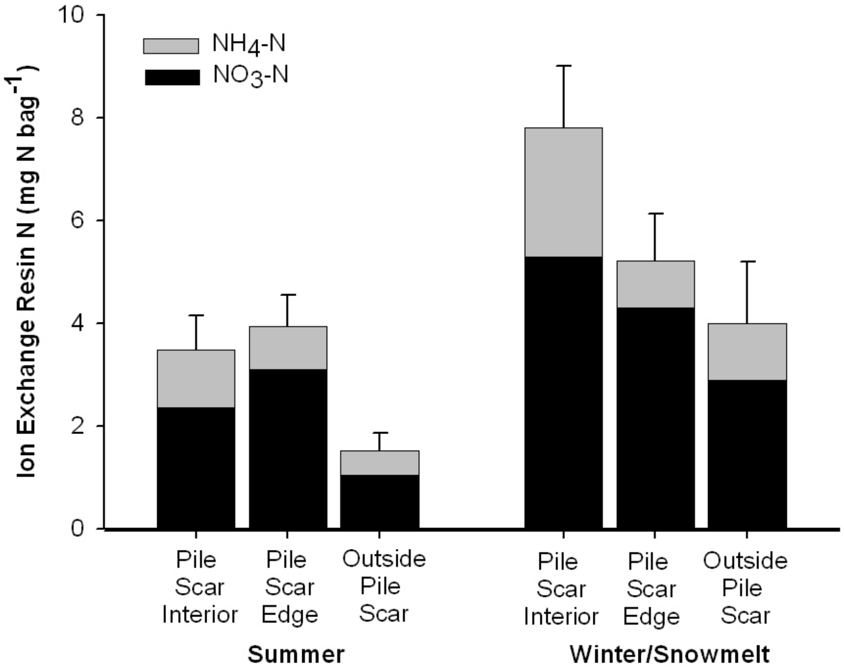


Figure 6. Ion exchange resin nitrogen at the Powerline and aspen sites (one year old pile scars) and at the Old site (two year old pile scars). Data are means and standard errors for the 14 untreated control scars.

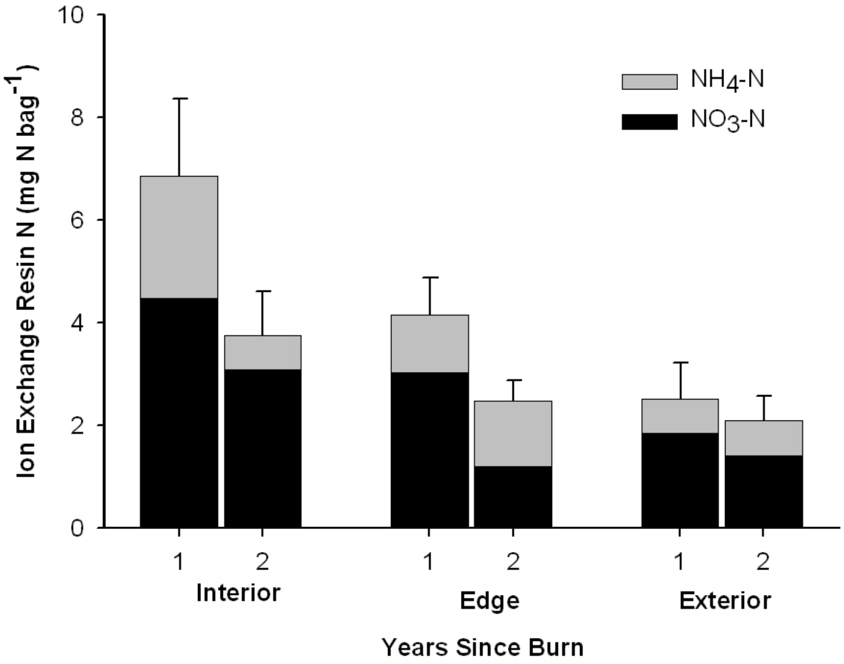


Figure 7. Native and exotic species richness and cover after slash pile burning. Data are means for the 14 untreated control pile scars (unseeded side only).

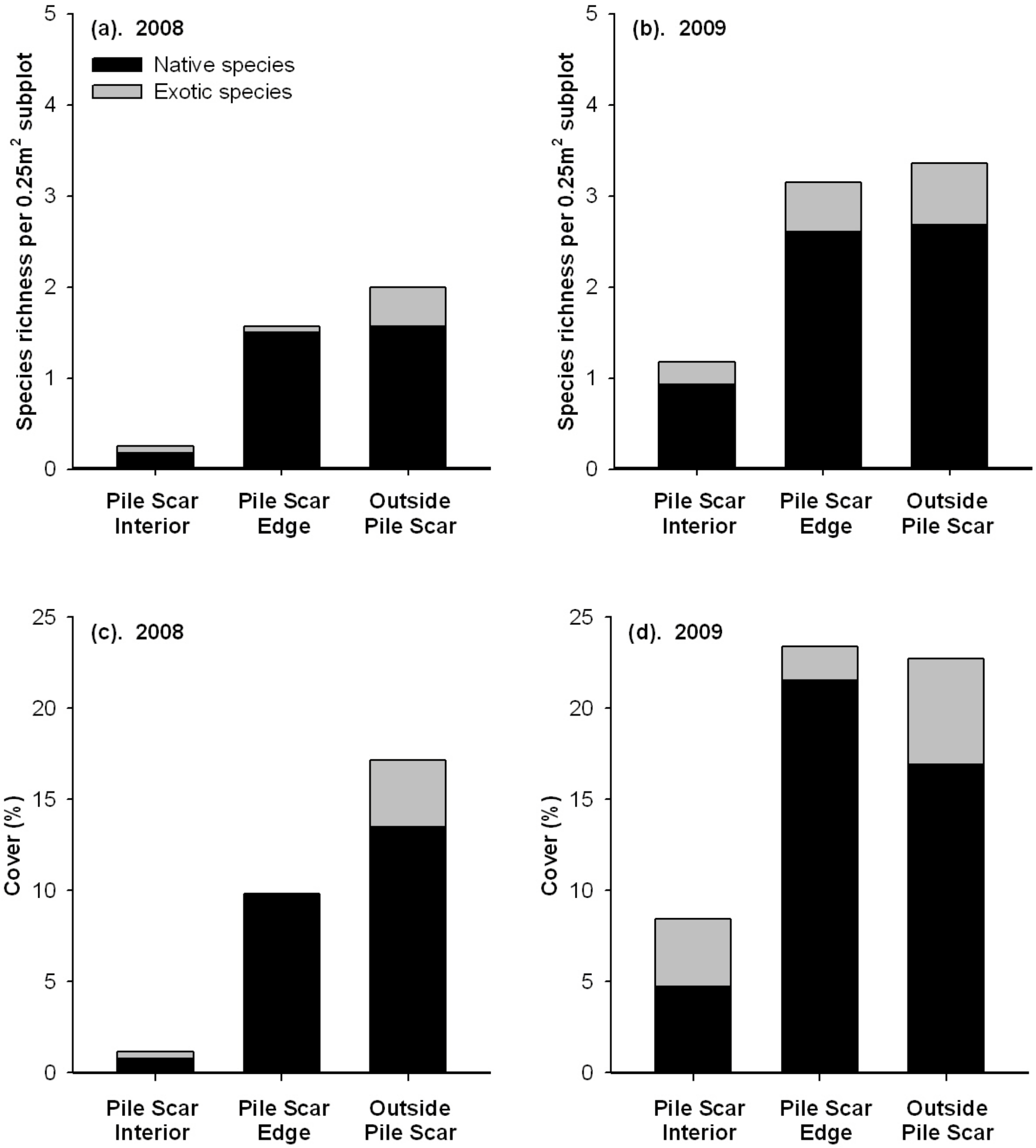


Figure 8. Restoration treatment impacts on summer and winter/snowmelt ammonium and nitrate concentrations at the three Reynolds Ranch sites. Data are means and standard errors.

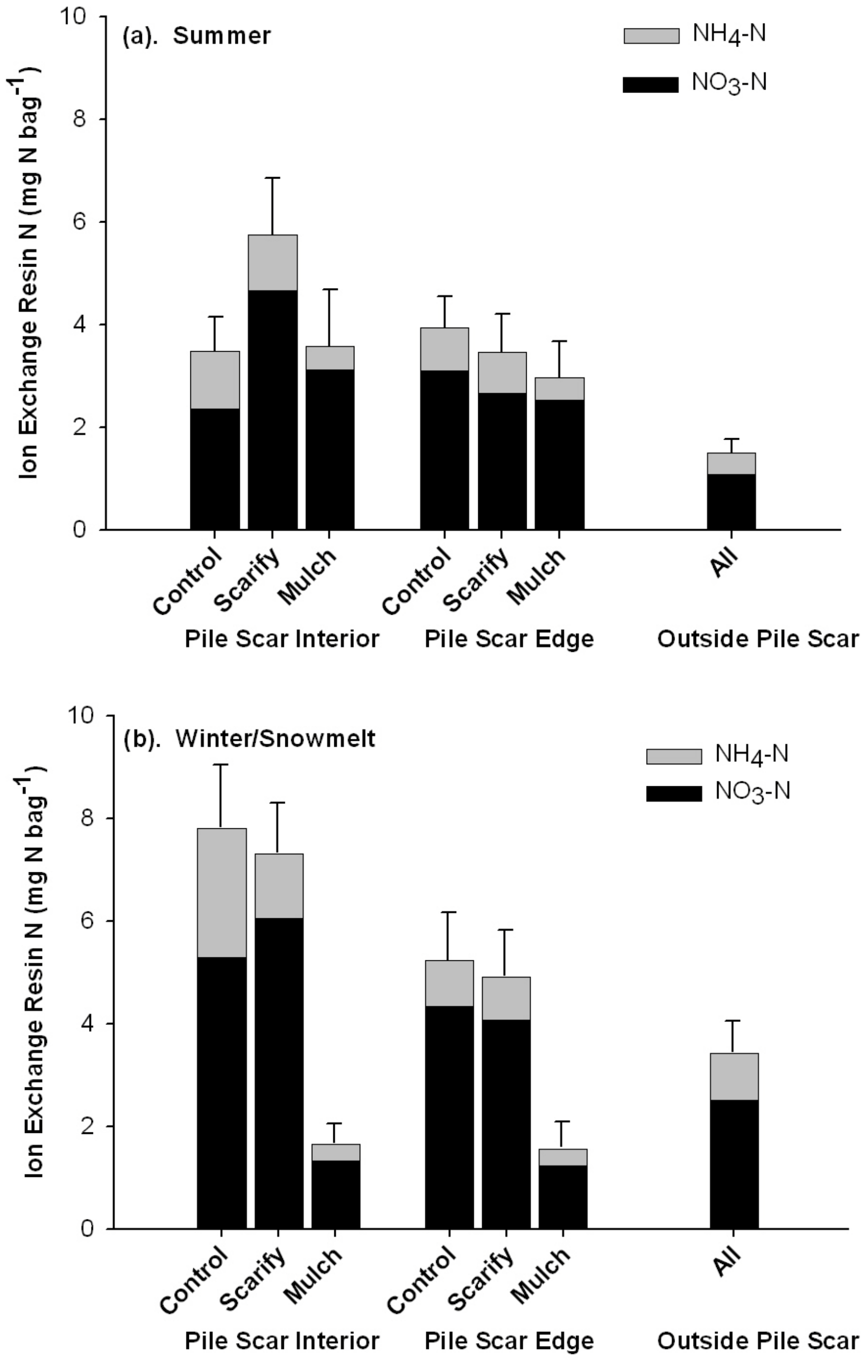


Figure 9. Restoration treatment impacts on native richness and cover in 2009 (thirteen months after treatment). Data are means and standard errors. Treatments are defined as follows: cont = control, scar = scarify, mul = mulch, sd = seed. Treatments had little to no impact on richness in 2008, one month after treatment, so data are not shown.

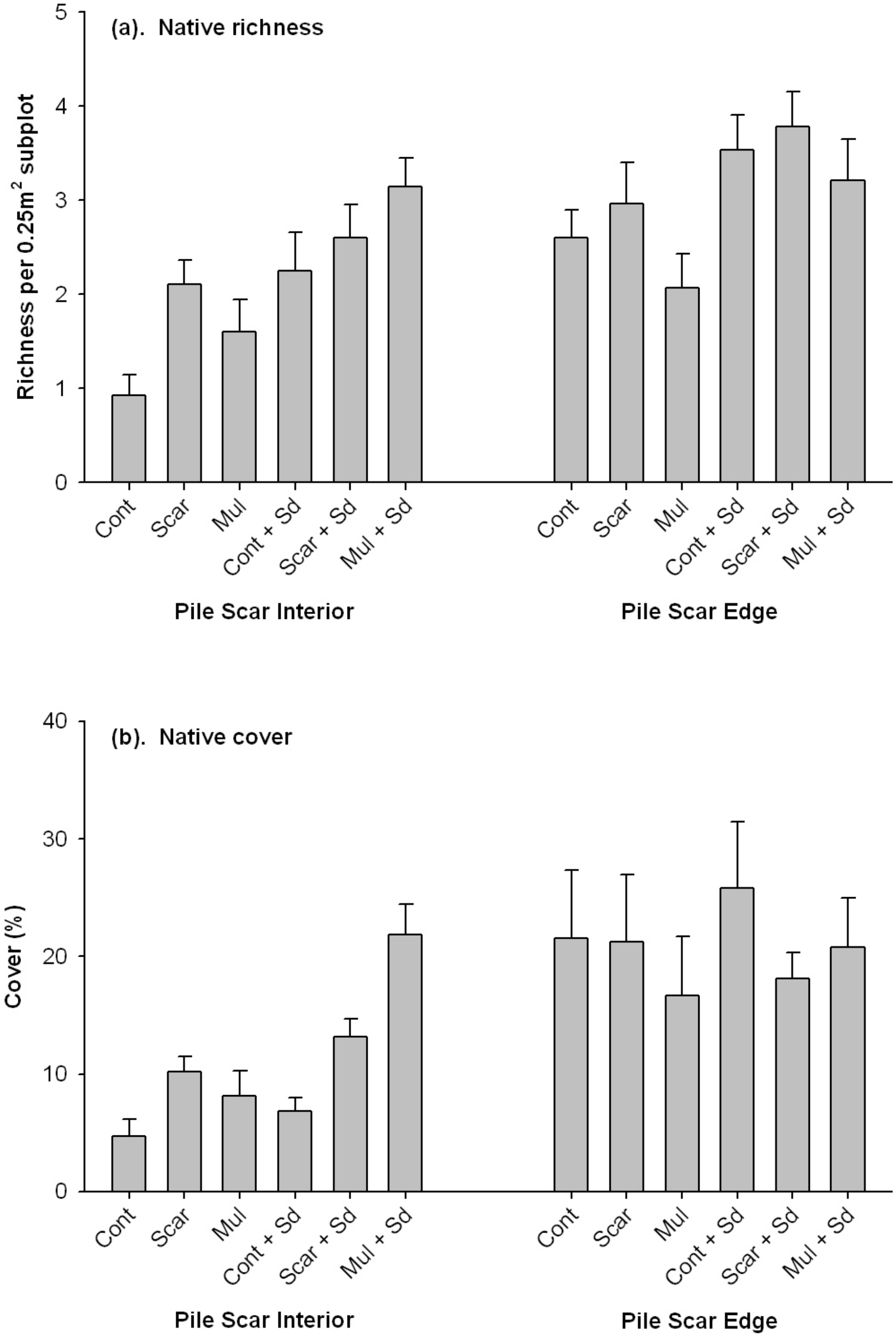


Figure 10. Restoration treatment impacts on exotic richness and cover in 2009 (thirteen months after treatment). Data are means and standard errors. Treatments are defined as follows: cont = control, scar = scarify, mul = mulch, sd = seed. Treatments had little to no impact on richness in 2008, one month after treatment, so data are not shown.

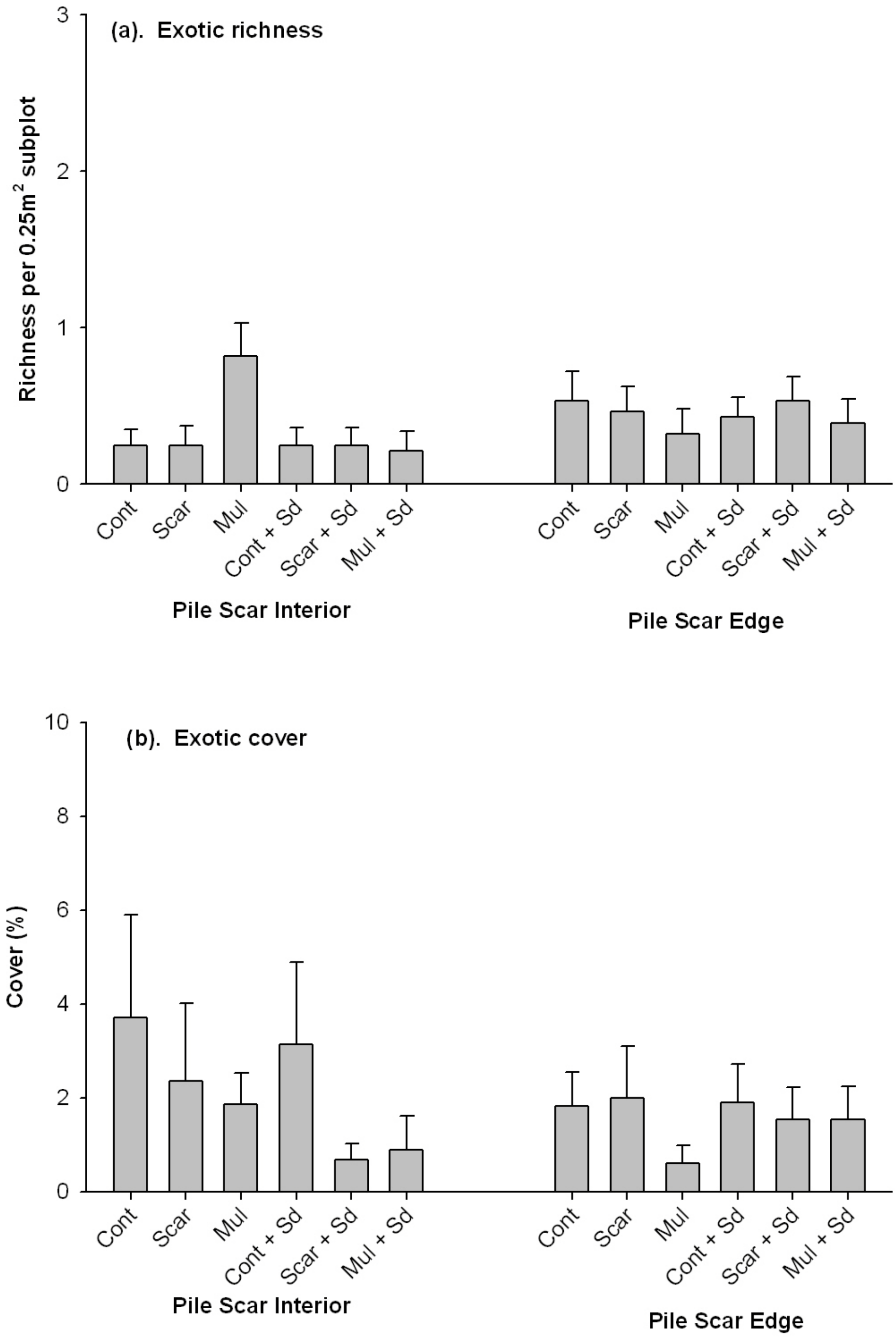


Figure 11. Response of vegetation in slash pile scars at Reynolds Ranch to control, scarify, and mulch treatments, with and without seeding. Photos were taken in July 2009, thirteen months after treatments were installed.

(a). Control

Seeded Unseeded

(b). Scarify

Unseeded Seeded

(c). Mulch

Unseeded Seeded

Figure 12. Seeded grass cover in the seeded halves of control, scarified, and mulched slash pile scars, by sampling location. Data are 2009 means and standard errors. There was no seeded grass cover in 2008, one month after seeding. NS = no significant differences exist among surface treatments.

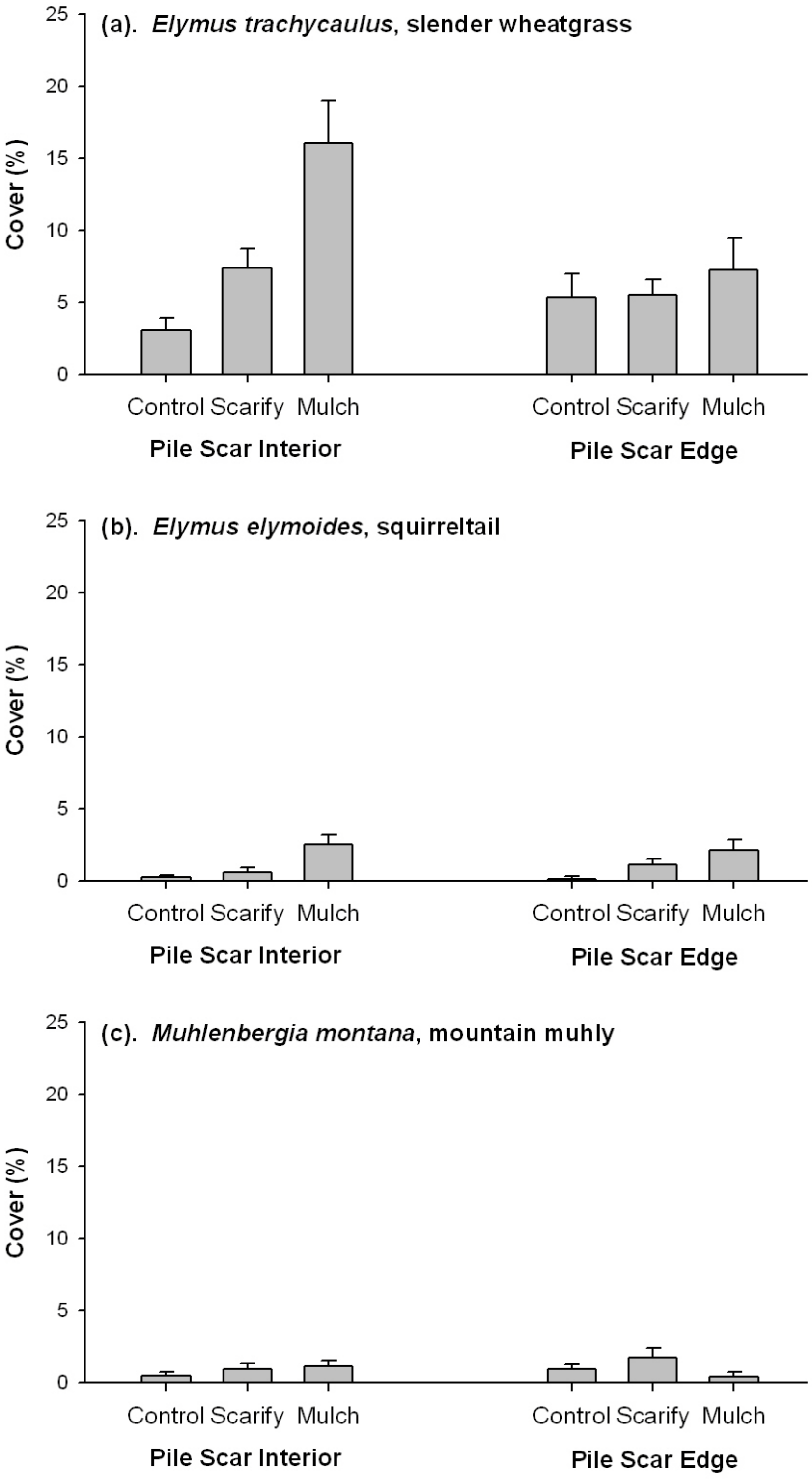


Figure 13. Locations of twenty slash pile sites in Larimer and Boulder County, Colorado. Three sites are on BCPOS land (Bald Mountain, Gold Hill, and Walker Ranch study areas), and 17 sites are on USFS land (Manhattan, Pingree Hill, Estes Valley, Peewink Mountain, and Sugarloaf study areas). Sites dominated by *P. ponderosa* are in blue and sites dominated by *P. contorta* are in red.

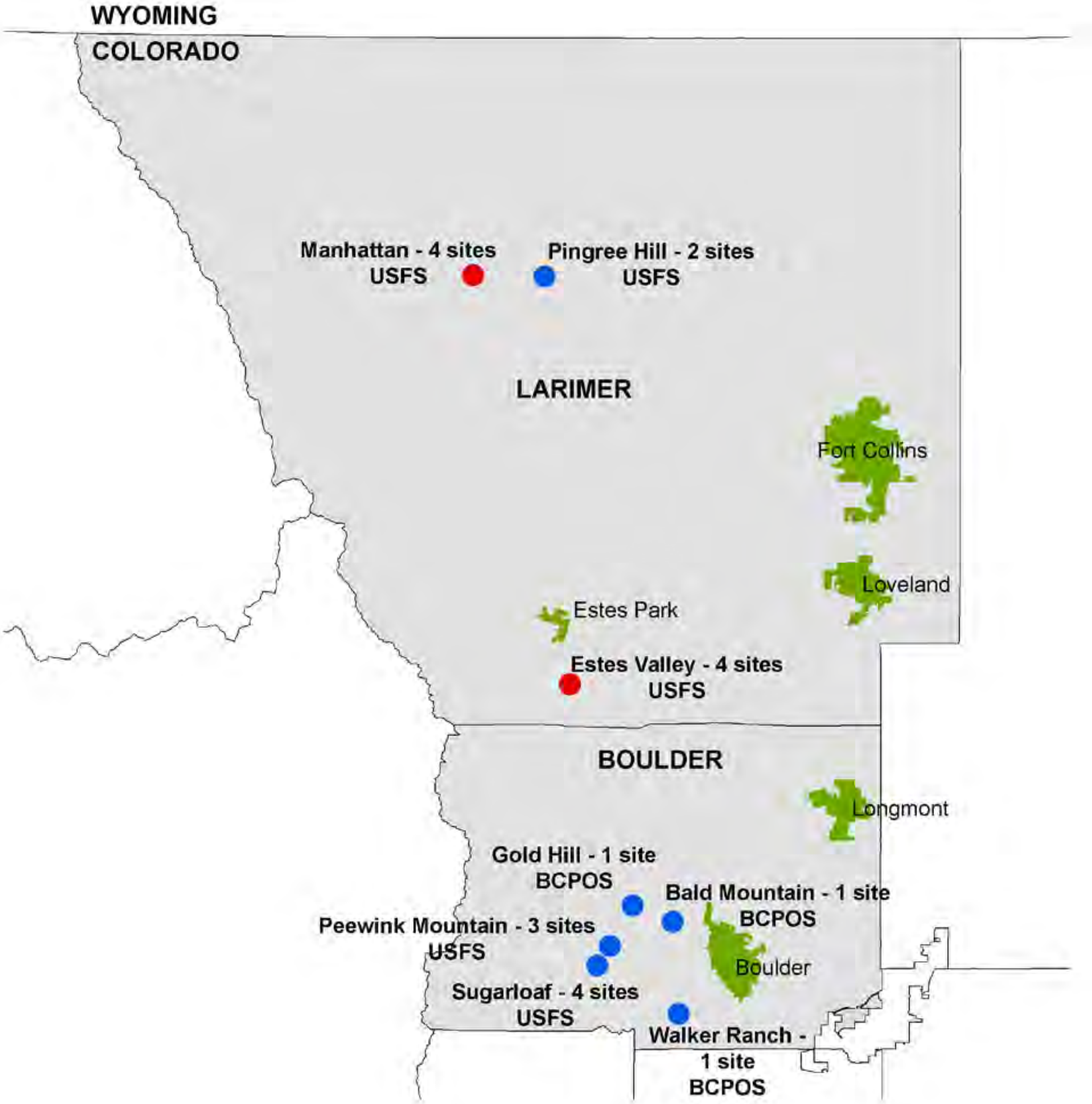


Figure 14. Treatments at Bald Mountain, Gold Hill, and Walker Ranch included scarify, slash mulch, mulch, and control. Each of these treatments was installed at two piles per site, with one pile also being seeded and the other pile remaining unseeded.

(a). Scarify treatment

(b). Slash mulch treatment

(c). Mulch treatment

(d). Control treatment