THESIS

EXPERIMENTAL RESTORATION TREATMENTS FOR BURN PILE FIRE SCARS IN CONIFER FORESTS OF THE FRONT RANGE, COLORADO

Submitted by

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ABSTRACT

EXPERIMENTAL RESTORATION TREATMENTS FOR BURN PILE FIRE SCARS IN CONIFER FORESTS OF THE FRONT RANGE, COLORADO

Drastic changes in soil physical, chemical, and biotic properties following slash pile burning and their lasting effects on vegetation cover have been well documented in ecosystems worldwide. However, processes that inhibit burn scar recovery are poorly understood as are the means for their rehabilitation. This study compared plant and soil responses to a number of surface treatments designed to alter microclimate, moisture infiltration, and nutrient status of recently burned slash piles along the Front Range of Colorado. Hand-applied surface manipulation treatments including: scarification, woodchip mulch, and tree branch mulch were compared with untreated burn scars, both with and without addition of a native species seed mix at 19 sites. Pile burning effects were observed by comparing fire scar centers with unburned reference areas while restoration treatment effectiveness was observed by comparing treated scar centers with untreated scar centers.

I found surface manipulations had little effect on vegetation recovery while seeding scars increased total plant biomass significantly. Woodchip mulch consistently increased soil moisture, decreased inorganic nitrogen availability, and inhibited plant regrowth in scars. Branch mulch and soil scarification showed no effect on plant regrowth and little effect on soil physical and chemical properties. Non-native species did not have a significant presence within slash scars and were no more prevalent in fire scar centers than reference conditions (unburned areas).

Recommendations based upon results of this study include seeding native species in fire scars to promote native species reestablishment.

ACKNOWLEDGMENTS

Thanks, first and foremost are due to my parents for the love and support they have shown throughout the years. Thank you for raising me to believe that I have the strength to complete anything to which I put my mind, no matter the difficulty. Tyler and I are invaluably lucky to have you as role models.

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1. INTRODUCTION

In conifer forests of Colorado and throughout western North America, pile burning of unmerchantable woody material is often used following hazardous fuel reduction treatments, forest-thinning operations, or as part of post-harvest site preparation activities (Covington *et al.*, 1991). Long burn durations and high fuel loading generate intense heat that is transferred downward into soil layers (Massman and Frank, 2004; Esquilin *et al.*, 2007; Meyer, 2009; Massman, 2012), altering soil physical and chemical traits (Korb *et al.*, 2004; Creech *et al.*, 2012), and often reducing or eliminating plant propagules (Haskins and Gehring, 2004; Korb *et al.*, 2004; Creech *et al.*, 2012). The negative consequences of burning slash are a concern for land managers charged with maintaining soil productivity and native plant diversity. Though many studies have examined alteration of native ecosystems from slash pile burning (Isaac and Hopkins, 1937; Austin and Baisinger, 1955; Scott and Burgy, 1956; Dyrness *et al.*, 1957; Morris, 1958; Dyrness, 1965; Vogl and Ryder, 1969; Klemmedson, 1976; Covington *et al.*, 1991; Giardina *et al.*, 2000; Haskins and Gehring, 2004; Esquilin *et al.*, 2007; Meyer, 2009; Johnson *et al.*, 2011; Creech *et al.*, 2012), very few (Korb *et al.*, 2004; Meyer, 2009; Fornwalt and Rhoades, 2011) have examined the effectiveness of rehabilitation treatments on fire scars.

Changes in soil physical, chemical, and biotic properties following slash pile burning and their lasting effects on vegetation cover have been well documented in western North American ecosystems. Combustion of organic material on the soil surface increases inorganic nitrogen (Covington *et al.*, 1991; Binkley *et al.*, 2003), which may create a nutrient-rich environment beneficial for weedy, invasive plant species (Haskins and Gehring, 2004; Korb *et al.*, 2004). Plant propagules are significantly diminished during slash pile burning (Clark and Wilson, 1994; Korb *et al.*, 2004; Creech *et al.*, 2012) resulting in a decrease in post-burning species diversity

(Clark and Wilson, 1994; Haskins and Gehring, 2004; Korb *et al.*, 2004; Creech *et al.*, 2012). Additionally, soil bacteria, fungi, and mycorrhizal assemblages are often significantly affected during slash pile burning (Haskins and Gehring, 2004; Korb *et al.*, 2004; Esquilin *et al.*, 2007). Water repellency may develop in the top few centimeters of soil during burning, further preventing seedling germination (Debano and Rice, 1973; DeBano, 1981; Everett *et al.*, 1995). Water repellent and bare mineral soil remaining after slash burning may cause erosion and nutrient loss from sites (DeBano, 1981). Lack of insulating vegetation cover and darkened soil surfaces can cause soils to exhibit extreme daily and seasonal moisture and temperature fluctuations (Kucera and Ehrenreich, 1962; Stoddard *et al.*, 2008; Fornwalt and Rhoades, 2011).

Slash pile burning typically creates a burn gradient due to heavy fuel loading in the center of the pile (Korb *et al.*, 2004; Esquilin *et al.*, 2007). Soil beneath the center of the pile heats more intensely and is associated with the greatest physical, chemical, and biological soil damage. Fire intensity declines near the edge of burn piles where organic and mineral soil layers are affected to a lesser extent.

Previous research indicates that simple rehabilitation techniques designed to ameliorate surface impacts may help speed the recovery of fire scars. To date, only three studies (Korb *et al.*, 2004; Meyer, 2009; Fornwalt and Rhoades, 2011) have physically manipulated slash pile burn scars to attempt rehabilitation. Korb *et al*. (2004) found that amending scars with seed and unburned soil increased native plant cover and decreased exotic plant cover in northern Arizona. Meyer (2009) found that seeding fire scars in Montana decreased exotic species during the first year and increased plant cover with a stronger effect when scars were also scarified. Soil impacts such as elevated pH, total N, total C, and total nitrification were at least somewhat mitigated by scarifying the soil and adding either commercial compost or on-site organic material (Meyer, 2009). Fornwalt and Rhoades (2011) were able to increase native plant cover and diversity in Colorado via addition of native seed and/or physical manipulation of fire scars. This study also reported a significant decrease in plant available nitrogen with the addition of woodchip mulch. Woodchip mulch has been shown to immobilize inorganic nitrogen following forest harvesting (Binkley *et al.*, 2003; Homyak *et al.*, 2008) and to minimize soil temperature extremes and retain more soil moisture during summer months in lodgepole pine forests (Rhoades *et al.*, 2012). Jacobs and Gatewood (1999) suggest that wood slash applied to degraded pinyon-juniper forest floor may create favorable microsites for establishment of grasses. Stoddard and coworkers (2008) found that wood slash applied to pinyon-juniper forests decreased soil movement and that combining slash with seed increased seedling germination and grass cover compared to control sites. Scarifying the soil surface is a common way to eliminate hydrophobic layers associated with combustion of the litter layer (Binkley and Matson, 1983; Thomas, 1996; Herrick *et al.*, 2001). Soil scarification may also increase infiltration rates and promote vegetation growth (USDA, 2000; Creech *et al.*, 2012).

Despite the widespread use of slash pile burning as a management tool, many managers lack information regarding whether rehabilitation treatments are necessary on resulting scars and if so, which techniques are most effective. The overall objective of this study was to evaluate effectiveness of surface rehabilitation treatments designed to mitigate negative effects of pile burning on soils and vegetation in conifer forests of the Front Range of Colorado. Specifically, I examined the effects of pile burning on 1) soil seedbank, 2) soil physical and chemical properties, and 3) vegetation cover and biomass. I also examined the effect of specific surface manipulation treatments (woodchip mulch, slash branches, scarification, or untreated control) and seeding (seeded or unseeded) on 1) water infiltration, 2) soil total carbon and nitrogen, 3) soil inorganic nitrogen, and 4) plant functional group (annual and biennial forb, perennial forb, annual and biennial grass, perennial grass, shrubs, and trees) responses in the first two years following treatment. I hypothesized that surface manipulations would be most effective at mitigating negative effects of slash pile burning on soil physical properties, while seeding scars would lead to increased vegetation growth as compared to untreated, control scars. In order to evaluate the effectiveness of rehabilitation treatments I examined 1) fire scar centers and unburned areas adjacent to each fire scar (reference areas/conditions) to characterize the type and amount of damage caused by burning slash and 2) differences among surface and seeding treatments and untreated fire scar interiors and edges in relation to untreated, control scars.

2. METHODS

2.1. Study Sites

The study was conducted at 19 sites on US Forest Service (Arapaho-Roosevelt National Forest) and Boulder County Open Space land distributed across the northern Front Range of Colorado, USA (Figure 1). Soils, topography, and aspect varied among sites (Table 1). Ponderosa pine (*Pinus ponderosa*) and Douglas-fir (*Pseudotsuga menziesii*) are the dominant overstory trees at 11 lower elevation sites (2,200 to 2,600 m) and lodgepole pine (*Pinus contorta*) is dominant at 8 higher elevation sites (2,700 to 2,800 m). Annual total precipitation averages 456 and 466 mm for climate stations located near the southern and northern extent of the study area, respectively. January minimum temperatures average -12.1^{o}C and -9.7^{o}C and July maximum temperatures average 24.0^{o}C and 23.1^{o}C for southern and northern extents of the study area, respectively (WRCC, 2013). The northern Front Range is comprised of Proterozoic, crystalline, granitic, and metamorphic bedrock that weathers into coarse-textured soils. In general, soils at the study site are classified as loamy skeletal Eutrocryepts, Dystrocryepts, and Haplustalfs (NRCS, 2013).

Trees at all sites were thinned and resulting tree tops, branches, and boles were hand piled in 2006 and 2007; piles were burned during winter months of 2007 and 2008, typically with snow cover on the ground to reduce risk of escaped fire. During fall 2009, approximately 2 years post-burn, 8 fire scars of similar size, shape, surrounding vegetation, and burn intensity (estimated from consumption of woody fuels) were selected at each study site and randomly assigned to 8 different rehabilitation treatment combinations. The rehabilitation treatments included 4 surface manipulations (untreated control, hand scarification, woodchip mulch

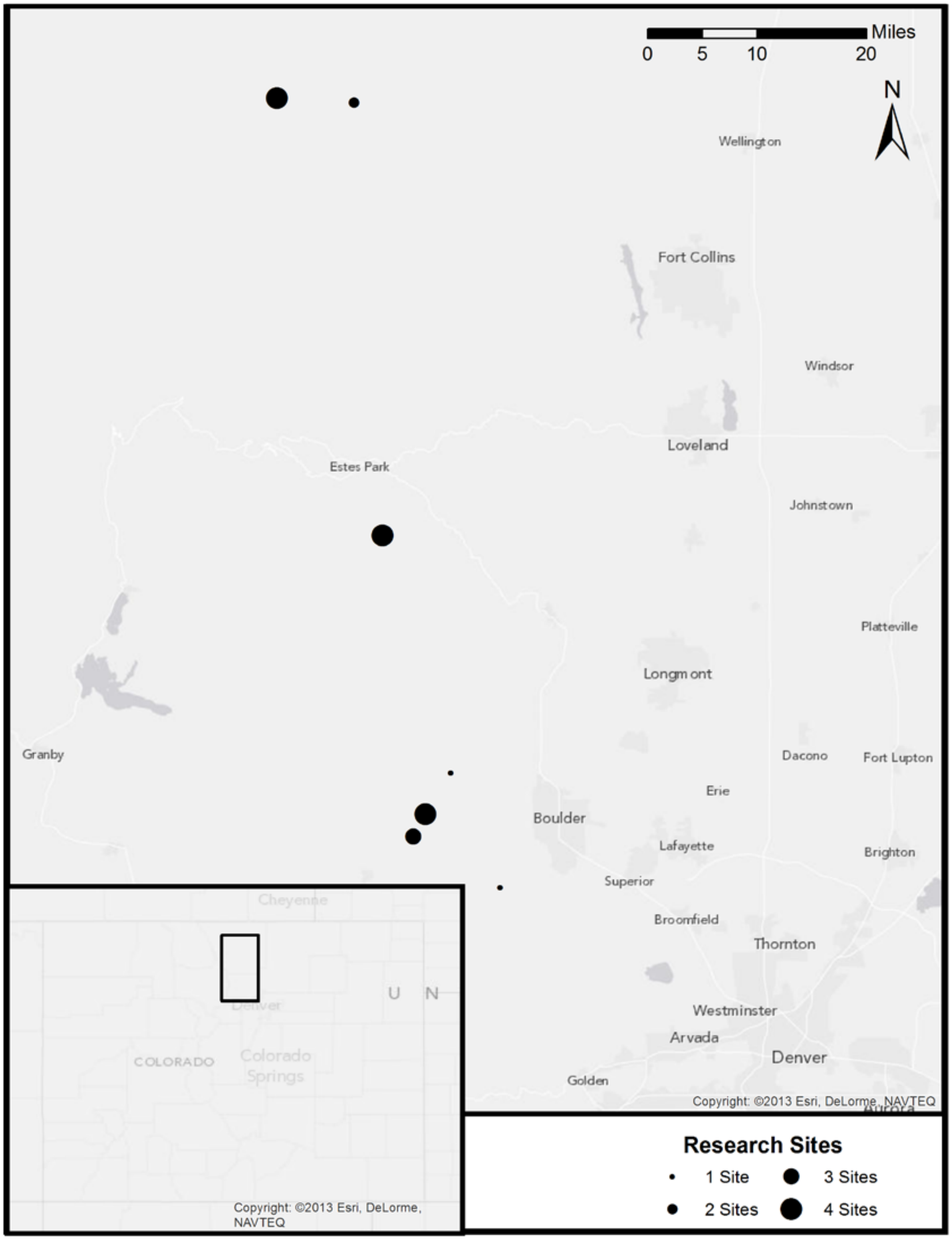

Figure 1. Site locations for slash pile burn study located within conifer forests of the Front Range of Colorado, USA. Larger circles indicate a greater number of sites.

Table 1. Site information for slash pile burn study located within conifer forests of the Front Range of Colorado, USA.

Site	Elevation (m)	UTM Coordinates (13N)	Average Fire Scar (m^2)	Soil Texture Class	Slope (%)	Aspect (degrees)
1	2768	458310, 4461598	15	Gravelly loam, sandy loam, very gravelly sandy loam	7	57
2	2757	458242, 4461863	14	Gravelly loam, sandy loam, very gravelly sandy loam	5	25
3	2772	458186, 4461737	13	Gravelly loam, sandy loam, very gravelly sandy loam	18	350
4	2766	458196, 4461816	11	Gravelly loam, sandy loam, very gravelly sandy loam	11	305
5	2582	484748, 7773368	12	Very gravelly sandy loam	4	183
6	2733	446843, 4510381	11	Sandy loam	11	133
7	2734	460049, 4506691	8	Sandy loam	9	93
8	2738	448117, 4509833	8	Sandy loam	2	190
9	2730	446852, 4510315	9	Sandy loam	7	125
10	2378	455329, 4510192	8	Gravelly sandy loam, gravelly coarse sandy loam	11	126
11	2415	454712, 4510439	10	Gravelly sandy loam, gravelly coarse sandy loam	29	14
12	2529	461630, 4428076	12	Very gravelly coarse sandy loam to very gravelly sandy loam	3	30
13	2513	461069, 4427967	9	Gravelly loam, very gravelly sandy loam, very cobbly sandy loam	10	311
14	2533	461524, 4428075	6	Very gravelly coarse sandy loam to very gravelly sandy loam	5	13
15	2588	463175, 4430476	9	Very gravelly coarse sandy loam to very gravelly sandy loam	4	277
16	2599	463210, 4430425	7	Very gravelly coarse sandy loam to very gravelly sandy loam	12	233
17	2598	462872, 4430425	7	Very gravelly coarse sandy loam to very gravelly sandy loam	8	76
18	2590	462887, 4430612	10	Very gravelly coarse sandy loam to very gravelly sandy loam	8	178
19	2214	471476, 4422398	11	Very gravelly sandy loam	16	311

addition, branch slash addition) applied alone or with a seeding treatment (8 treatment combinations). The scarification treatment was conducted using a McLeod fire tool to till the upper 10 cm of the fire scar; the surface was left roughened. Chips for the woodchip mulch treatment were generated on-site using slash produced from previous thinning operations and covered fire scars approximately 6-8 cm in depth; chip pieces were relatively uniform (~ 2-10 cm long by 1-2 cm thick). Tree branches from thinning operations were stacked on fire scars to create approximately 50% shade cover for the branch slash treatment.

Scars treated with seed received a mixture of 32 species native to conifer forests of Colorado's northern Front Range. Seeds included 20 forb species (annual, biennial, and perennial), 10 grass species (perennial), and 2 shrub species (Table 2). Seeds were hand collected from local populations or purchased from regional suppliers. All hand-collected seeds were tested for purity, germination, and presence of weeds by the Colorado Seed Lab at Colorado State University. The mixture was hand-broadcast at a rate of 2,700 PLS (pure live seed) m^{-2}. Seeding rates for each species were determined based on expected field emergence and competitive ability. A garden rake was used to roughen a 1 cm seedbed prior to seeding. Fire scars were seeded prior to mulching treatments but after the scarification treatment; the seedbed was then tamped to firm the soil to improve soil to seed contact. Data was collected from treated scars during 2010 and 2011. Treatments were added to scars approximately 2 years post-burn (2009) and data was collected 3 and 4 years post-burn (2010, 2011).

Table 2. List of species and their characteristics used in seeding mix for rehabilitation treatments applied to fire scars in Colorado. Characteristics are growth form (f-forb; g-graminoid; s-shrub) and duration (p-perennial; b-biennial; a-annual).

Scientific Name	Family	Seeding Rate (PLS m^{-2})	Growth Form	Duration
Allium cernuum	Liliaceae	108.0	f	p
Artemisia frigida	Asteraceae	108.0	f	p
Artemisia ludoviciana	Asteraceae	108.0	f	p
Bouteloua gracilis	Poaceae	81.0	g	p
Campanula rotundifolia	Campanulaceae	67.5	f	p
Chamerion angustifolium	Onagraceae	162.0	f	p
Chenopodium fremontii	Chenopodiaceae	148.5	f	a
Chenopodium leptophyllum	Chenopodiaceae	337.5	f	a
Danthonia spicata	Poaceae	40.5	g	p
Elymus elymoides	Poaceae	54.0	g	p
Elymus lanceolatus	Poaceae	54.0	g	p
Elymus trachycaulus	Poaceae	54.0	g	p
Eriogonum umbellatum	Polygonaceae	108.0	f	p
Festuca arizonica	Poaceae	81.0	g	p
Grindelia squarrosa	Asteraceae	81.0	f	a,b,p
Harbouria trachypleura	Apiaceae	60.8	f	p
Heterotheca villosa	Asteraceae	108.0	f	p
Koeleria macrantha	Poaceae	81.0	g	p
Liatris punctata	Asteraceae	81.0	f	p
Lupinus argenteus	Fabaceae	81.0	f	p
Muhlenbergia montana	Poaceae	54.0	g	p
Pascopyrum smithii	Poaceae	27.0	g	p
Penstemon virens	Scrophulariaceae	108.0	f	p
Phacelia heterophylla	Hydrophyllaceae	24.3	f	b,p
Poa fendleriana	Poaceae	54.0	g	p
Potentilla fissa	Rosaceae	54.0	f	p
Potentilla hippiana	Rosaceae	108.0	f	p
Ribes cereum	Grossulariaceae	86.4	s	p
Rosa woodsii	Rosaceae	94.5	s	p
Solidago simplex	Asteraceae	27.0	f	p
Symphyotrichum porteri	Asteraceae	20.3	f	p
Thermopsis divaricarpa	Fabaceae	37.8	f	p

2.2. Measurements

Scars were sampled at three positions to capture differences in soil and vegetative properties: the center of the scar (center), along the edge of the scar boundary (edge), and 2 meters outside the scar (reference condition) (Figure 2). Scar edges were permanently marked with nails after slash pile burning for annual relocation.

Soil was collected from untreated scars at all 19 sites during November 2009 to determine the existing seedbank across sites and within the burn gradient. Surface soil was sampled from the top 10 cm of fire scar centers, edges, and reference areas with a 7.3-cm diameter soil corer. Three subsamples were composited per position; samples were sieved (5 mm mesh) and stored at 4^{o}C for 5 months to vernalize seeds recently added to the seedbank. Half the sieved soil was spread evenly atop a 1:1 $^{v}/_{v}$ mixture of potting soil and sand in a 30.0- x 54.3-cm planting tray. Planting trays were misted every 30 minutes for 12 hours a day, warmed from below to a constant 24^{o}C, and the photoperiod was extended to 16 hours per day with artificial lighting. Germinating seedlings were grown until species identification could be confirmed and then removed. Trays were maintained for 6 months until new seedlings ceased to emerge. Control trays with a 1:1 $^{v}/_{v}$ mix of potting soil and sand were used to determine if there was any seed rain within the greenhouse (none was detected). Seed density was calculated as observed number of germinates in seedbank samples per surface area sampled.

Water infiltration was measured during June 2010 and September 2011 at all 19 sites using a field infiltrometer designed to assess soil changes after wildfire (Decagon Devices, Pullman, WA). Volume of water infiltrated during a 60 second period was recorded at the soil surface (0 cm), 2 cm, and 4 cm after removing forest litter (Lewis *et al.*, 2006). Changes in soil

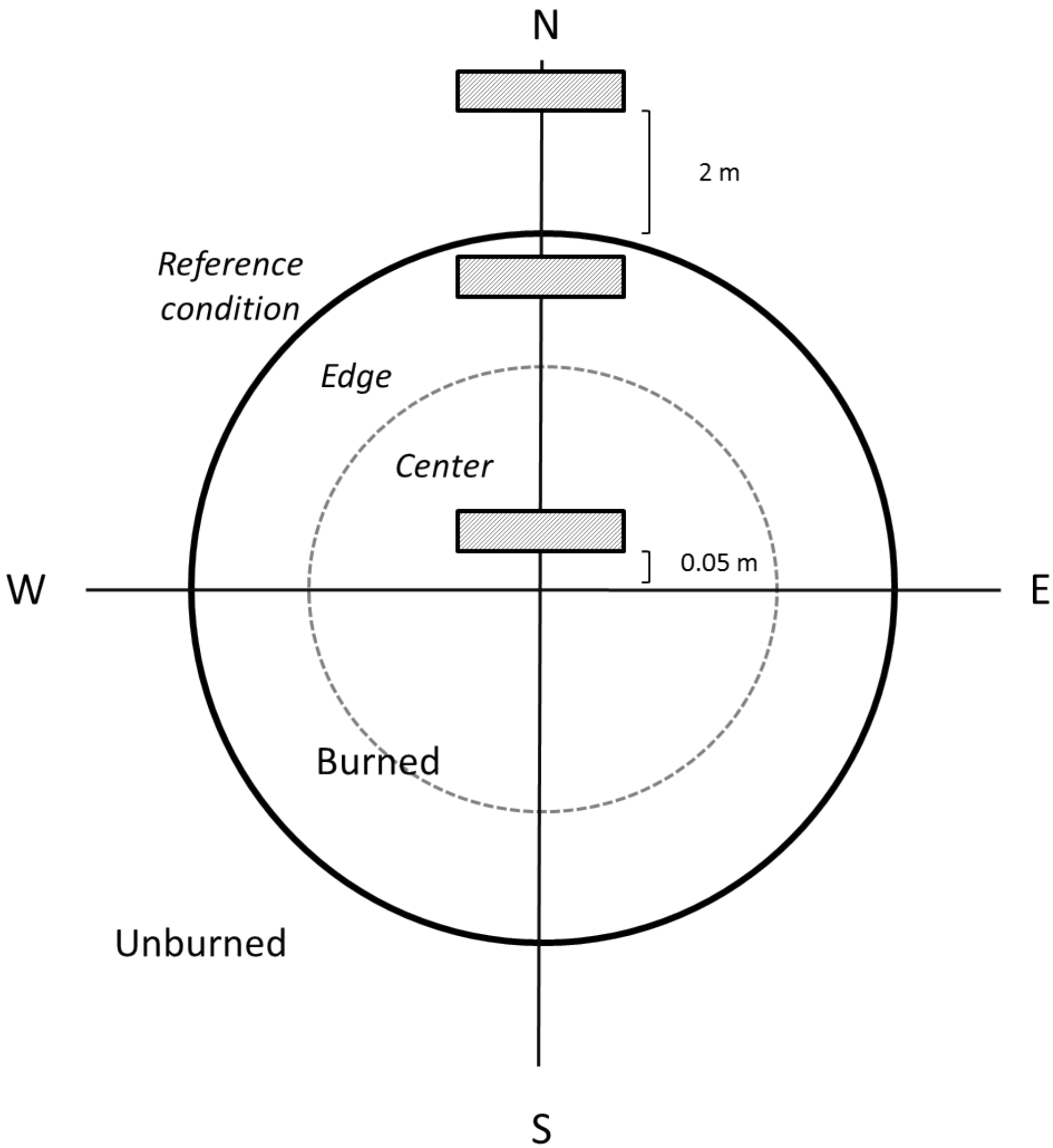

Figure 2. Schematic diagram of vegetation sampling plots for fire scar study located within conifer forests of the Front Range of Colorado, USA (not to scale).

structure and erodability were assessed with a qualitative index of soil aggregate stability (Herrick *et al.*, 2001) at 19 sites during June 2010. Replicate 1-2 cm diameter soil aggregates from the upper 5 cm of mineral soil (6 per position) were tested and subsample data was composited for each position. Mineral soil (0-10 cm depth) samples composited within each fire scar position collected at all 19 sites during September 2011 were air dried, sieved (2 mm mesh), ground, and analyzed for total Carbon and Nitrogen using dry combustion (Leco Corp., St. Joseph, MI). Soil remaining from seedbank testing (half of each sample) was extracted using 25 mL ammonium acetate and analyzed for cations (Ca, K, Mg, Al) at Colorado State University's Soil and Water Testing Lab. Soil pH was measured in a 1:1 $^{v}/_{v}$ mixture of soil (collected from 19 sites during November 2009) and 0.01M $CaCl_2$ (Thomas, 1996) using a temperature-corrected glass electrode (Accumet Model 50, Thermo Fisher Scientific Inc., Pittsburgh, PA).

Plant-available nitrogen was compared among treatments and positions using ion exchange resin (IER) bags (Binkley and Matson, 1983) over the summer months and at eight of the 19 sites distributed across the entire study area. Resin bags were in the ground from June 2010 until September 2010 and from June 2011 until September 2011. Resin bags were inserted into mineral soil within fire scars at a depth of 5-10 cm. Duplicate resin bags were placed in center, edge, and reference positions at each fire scar. Resin bags consisted of a 1:1 $^{v}/_{v}$ mixture of cation (Sybron Ionic C-249, Type 1 Strong Acid, Na form, Gel Type) to anion (Sybron Ionic ASB-1P Type 1, Strong Base OH form, Gel Type) exchange resin beads. After incubation, resins were extracted with a 2 M KCl solution, shaken for 60 minutes, filtered (Cat No: 09-790C), and frozen until analysis. Nitrate and ammonium were measured in extracts using a Lachat QuickChem 7000 Flow Injection Analyzer (Lachat Company, Loveland, CO).

Volumetric water content was measured in every fire scar at all 19 sites during June and September of 2010 and 2011 with a handheld instrument (CD 620, HydroSense, Campbell Scientific, Logan, UT). Four soil water measurements were taken and averaged for each position (center, edge, reference).

Vegetation cover and above-ground biomass were sampled in early August 2010 and 2011 within 0.25- x 0.75-m (0.19 m^2) sampling frames in all treatments at all 19 sites. Sample frames were located within center, edge, and reference positions along transects (Figure 2). Transects were shifted each year to avoid effects of previous year's sampling efforts. One frame was used per scar for fire scars that measured ≤ 9 m^2 and 2 frames were used for larger scars. Cover of plants by species, bare mineral soil, litter, and rock was estimated using a point intercept method. Live plant biomass was clipped by species, dried at 55^{o}C until a constant mass was reached, and weighed.

2.3. Statistical analysis

I analyzed the effects of 1) slash pile burning and 2) restoration treatments on soil chemical (pH, soil cations, total carbon and nitrogen, and inorganic nitrogen (ammonium + nitrate)) and physical (soil aggregate stability, water infiltration, and soil moisture) properties as well as the soil seedbank, total percent vegetation cover, and total plant biomass for each sampling period separately. Transformations were used to approximate normality and Friedman's non-parametric test was used when normality could not be approximated. All analyses were completed using SAS version 9.3 (SAS Institute, Cary, NC) with α=0.05.

In the first analysis, positions (center, edge, and reference) associated with untreated control scars (no surface treatment or seeding) were compared to assess effects of slash pile burning on each response variable with a split-plot analysis of variance using restricted maximum likelihood estimation (REML ANOVA) in PROC GLIMMIX. The Kenward-Rogers denominator degrees of freedom method was used to adjust for heterogenous variances. Positions for each scar (center, edge, reference) were treated as subplots. Because the three positions could not be randomly assigned and were not equidistant from one another, I tested three error covariance structures (toeplitz, heterogenous toeplitz, and compound symmetry) and used the structure resulting in the best model fit based on small sample Akaike's Information Criterion (AIC_C).

Next, the effects of surface manipulations and seeding treatments and position were assessed for each response variable to determine relative effectiveness of rehabilitation treatments. I used a randomized complete block split-plot REML ANOVA with blocks=sites and subplots=positions in PROC GLIMMIX. The Kenward-Rogers denominator degrees of freedom method was used to adjust for heterogenous variances. The best subplot error covariance structure was determined as described above.

3. RESULTS

3.1. Effects of pile burning on soils and vegetation

Burning slash increased soil pH in scar centers and to a lesser extent, along the scar edge ($p<0.001$, Figure 3a) relative to unburned reference areas. Burning slash piles also reduced soil aggregate stability in scar centers as measured June 2010 ($p<0.001$, Figure 3b). Four years post-fire (2011), total carbon and total nitrogen were significantly lower in the center of scars relative to reference conditions ($p<0.001$, Figure 3c; $p=0.004$, Figure 3d). During the first year of the study (2010), significantly less water infiltration occurred just below the soil surface in scar centers as compared to reference areas ($p<0.001$, Figure 4). Soils in scar centers held significantly less moisture than reference areas during June measurements and more moisture during September measurements ($p=0.020$, $p=0.017$, Table 3). Calcium, potassium, and magnesium concentrations measured one year post-burn were all greater in scar centers as compared to reference areas ($p=0.003$; $p<0.001$; $p<0.001$, Table 3).

Seedbank data showed scar centers with a 7.5-fold decrease in seed density as compared to reference conditions ($p<0.001$; Table 4). Perennial graminoid and perennial forb seed density was significantly reduced in scar centers when compared to reference areas ($p<0.001$, $p<0.001$ respectively). Only 2 noxious species (mullein and Canada thistle) were found in seedbank samples; however, no significant difference between positions were observed for these species ($p=0.174$).

Total plant biomass was diminished in scar centers as compared to reference areas during the first year of this study ($p=0.031$, Table 5). However, there were no significant differences discovered between specific plant communities once posthoc tests were run.

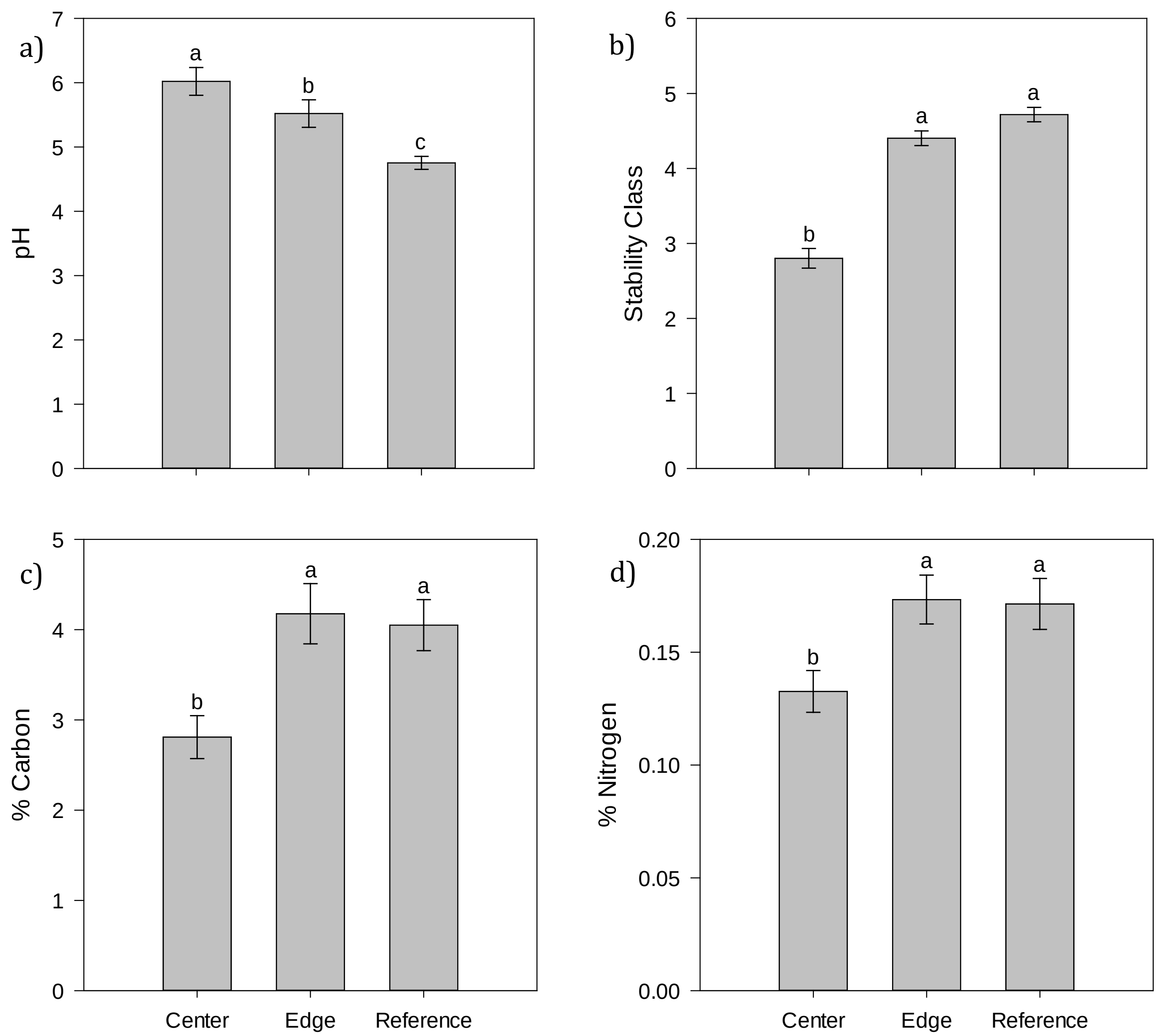

Figure 3. Effect of slash pile burning on soil properties within conifer forests of the Front Range of Colorado, USA. Soil pH measurements (a) (data collected 2 years post-burn) and soil aggregate stability classifications (b) (data collected approximately 3 years post-burn), total carbon (c) and nitrogen (d) (data collected approximately 4 years post-burn) by position. Data are for untreated fire scars only. Different letters indicate significant differences between positions at p=0.05 using Tukey's posthoc test on transformed data when necessary to approximate normality, error bars are ± 1 S.E. To approximate normality the square root of pH data was used, a non-parametric test was used for soil aggregate stability, and the log of total carbon and nitrogen data was used.

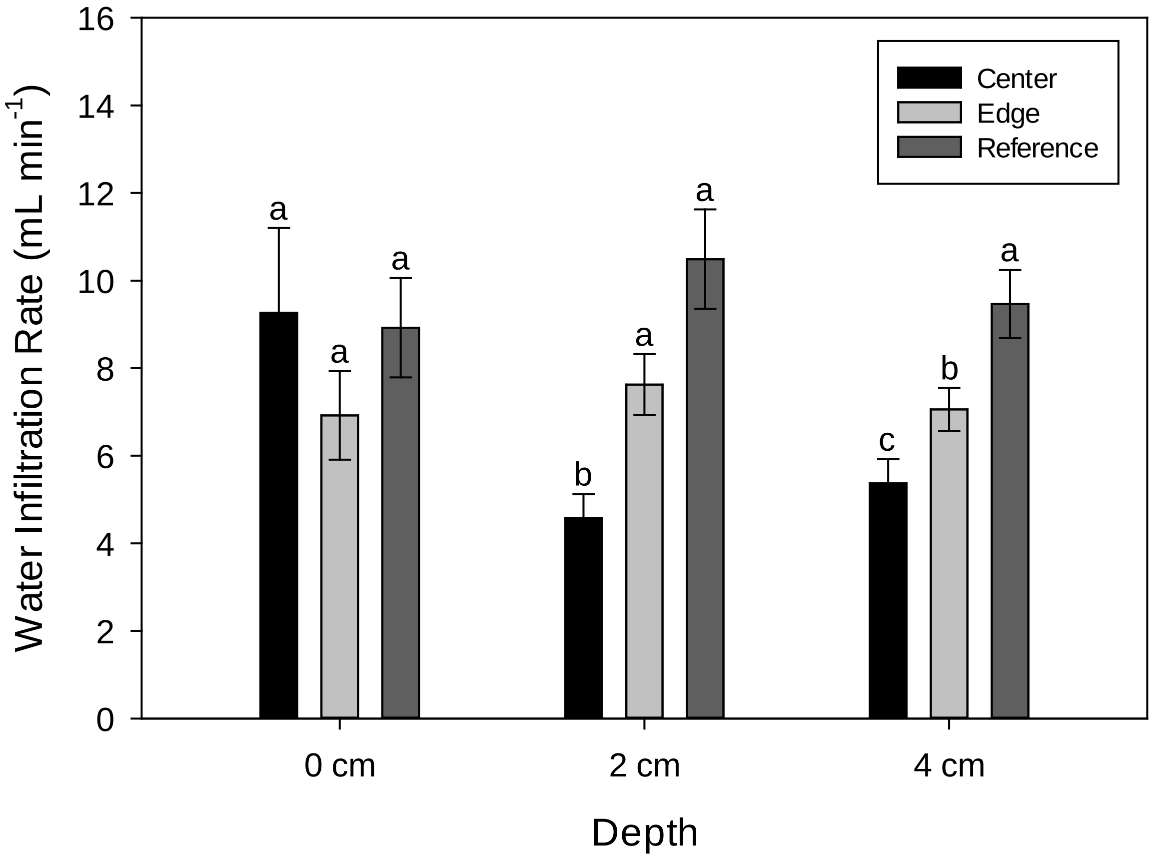

Figure 4. Effect of slash pile burning on water infiltration within conifer forests of the Front Range of Colorado, USA. Data was collected approximately 3 years post-burn by position for untreated fire scars only. Different letters indicate significant differences between positions at p=0.05 using Tukey's posthoc test on untransformed data, error bars are ± 1 S.E. Friedman's non-parametric test was used for water infiltration data as data was highly skewed.

Table 3. Effect of pile burning on soil properties within conifer forests of the Front Range of Colorado, USA. Soil pH and concentration of soil cations (Al, Ca, K, Mg) were measured 2 years post-burn (2009); soil aggregate stability, soil moisture (time domain reflectometry), and soil infiltration (volume of water lost in mL at 3 separate soil depths) were measured at untreated scars in 2010 (3 years post-burn). Total soil carbon and nitrogen were measured at untreated scars during 2011 (4 years post-burn) in untreated, control scars only. Transformations to approximate normality were used on pH (square root), soil cations (log), and fall soil moisture data (log), while non-parametric tests were used to test effects of pile burning on soil aggregate stability, spring soil moisture, and soil infiltration data. Significant position effects through ANOVA are indicated in bold. Mean values (± 1 S.E.) shown next to ANOVA results, lowercase letters following standard errors indicate significant differences by position. All differences significant at the p=0.05 level as indicated by Tukey's posthoc test following significant ANOVA testing. Note: significant effect among positions for fall soil moisture was not significant following multiple comparison posthoc tests.

			Position					
Variable			Center		Edge		Reference	
	Statistic	*Probability*						
pH	29.20	**<0.001**	6.02 (0.22)	c	5.52 (0.21)	b	4.75 (0.1)	a
Al *(ppm)*	2.53	0.101	48.82 (11.71)	a	52.46 (14.86)	a	65.16 (14.48)	a
Ca *(ppm)*	7.13	**0.003**	333.61 (31.44)	a	312.46 (33.4)	a	251.23 (24.41)	b
K *(ppm)*	15.66	**<0.001**	60.26 (5.94)	a	51.51 (3.76)	a	34.45 (2.17)	b
Mg *(ppm)*	15.66	**<0.001**	38.94 (3.36)	a	37.16 (2.35)	a	28.89 (1.75)	b
Total C *(%)*	10.37	**<0.001**	2.81 (0.24)	b	4.18 (0.33)	a	4.05 (0.28)	a
Total N *(%)*	6.34	**0.004**	0.13 (0.01)	b	0.17 (0.01)	a	0.17 (0.01)	a
C:N	16.52	**<0.001**	21.23 (0.96)	b	23.93 (0.98)	a	23.84 (1.18)	a
Aggregate stability	147.29	**<0.001**	2.8 (0.13)	b	4.4 (0.1)	a	4.72 (0.1)	a
Soil moisture (fall) *(%)*	8.21	**0.017**	6.3 (0.32)	a	5.64 (0.19)	a	5.7 (0.19)	a
Soil moisture (spring) *(%)*	4.36	**0.020**	10.34 (0.58)	b	11.79 (0.92)	a	11.79 (0.82)	a
Infiltration - depth 0cm *(mL min^{-1})*	2.27	0.321	9.26 (1.94)	a	6.92 (1.01)	a	8.92 (1.13)	a
Infiltration - depth 2cm *(mL min^{-1})*	20.25	**<0.001**	4.58 (0.54)	c	7.62 (0.7)	b	10.49 (1.14)	a
Infiltration - depth 4cm *(mL min^{-1})*	20.63	**<0.001**	5.37 (0.55)	b	7.05 (0.49)	b	9.46 (0.78)	a

Table 4. Effect of slash pile burning on plant propagules in soils within conifer forests of the Front Range of Colorado, USA. Seed density (m^2) was collected by position approximately 2 years post-burn (2009) from untreated fire scars. Data transformation was used on total seed density data (square root transformed) while non-parametric tests were used for all functional groups. Mean values (germinates m^{-2}) (± 1 standard error) shown by position. Position effects for untransformed data used the Cochran-Mantel-Haenszel statistic. Different letters indicate significant differences between positions at p=0.05 using Tukey's posthoc test. Species that could not be identified were analyzed in the total vegetation analysis but were removed during analysis of functional groups, accounting for any discrepancy between functional group totals and vegetation totals. Noxious taxa shown in italics. Note: significant effect among positions for annual and biennial forbs was not significant following multiple comparison posthoc tests.

	Position					
Taxa	Center		Edge		Reference	
			Number germinates m^{-2}			
Annual and biennial forb						
Chenopodium album	0.00 (0.00)		15.14 (15.14)		0.00 (0.00)	
Chenopodium capitatum	15.14 (15.14)		0.00 (0.00)		0.00 (0.00)	
Chenopodium leptophyllum	5.05 (5.05)		0.00 (0.00)		0.00 (0.00)	
Conyza canadensis	10.09 (10.09)		45.41 (24.63)		35.32 (20.95)	
Gnaphalium exilifolium	35.32 (25.58)		287.62 (197.34)		348.17 (264.78)	
Lactuca serriola	10.09 (10.09)		5.05 (5.05)		0.00 (0.00)	
Verbascum thapsus	*15.14 (11.01)*		*70.64 (55.22)*		*45.41 (23.51)*	
Total	**90.83 (44.06)**	***a***	**423.86 (196.07)**	***a***	**428.90 (260.83)**	***a***
Perennial forb						
Achillea millefolium	5.05 (5.05)		15.14 (15.14)		5.05 (5.05)	
Allium cernuum	0.00 (0.00)		5.05 (5.05)		25.23 (9.87)	
Antennaria parvifolia	0.00 (0.00)		50.46 (25.67)		136.24 (120.49)	
Androsace septentrionalis	0.00 (0.00)		141.29 (113.33)		65.60 (51.82)	
Artemisia campestris	10.09 (10.09)		10.09 (6.92)		15.14 (11.01)	
Artemisia frigida	10.09 (10.09)		15.14 (11.01)		75.69 (60.66)	
Arabis hirsuta	0.00 (0.00)		0.00 (0.00)		20.18 (15.67)	

Taxa	Position					
	Center		Edge		Reference	
Perennial forb (con’t)						
Artemisia ludoviciana	0.00 (0.00)		20.18 (9.16)		75.69 (41.70)	
Campanula rotundifolia	0.00 (0.00)		35.32 (22.2)		5.05 (5.05)	
Chamerion angustifolium	10.09 (10.09)		10.09 (6.92)		0.00 (0.00)	
Cirsium arvense	*0.00 (0.00)*		*10.09 (10.09)*		*5.05 (5.05)*	
Epilobium ciliatum	5.05 (5.05)		0.00 (0.00)		5.05 (5.05)	
Erysimum capitatum	0.00 (0.00)		0.00 (0.00)		5.05 (5.05)	
Fragaria virginiana	0.00 (0.00)		10.09 (10.09)		5.05 (5.05)	
Heterotheca villosa	5.05 (5.05)		10.09 (6.92)		5.05 (5.05)	
Mertensia laceolata	0.00 (0.00)		5.05 (5.05)		0.00 (0.00)	
Packera fendleri	0.00 (0.00)		0.00 (0.00)		5.05 (5.05)	
Penstemon virens	0.00 (0.00)		20.18 (9.16)		5.05 (5.05)	
Potentilla fissa	5.05 (5.05)		75.69 (38.33)		121.10 (42.82)	
Pseudognaphalium canescens	0.00 (0.00)		0.00 (0.00)		5.05 (5.05)	
Sedum lanceolatum	0.00 (0.00)		0.00 (0.00)		5.05 (5.05)	
Solidago nana	0.00 (0.00)		35.32 (22.2)		20.18 (20.18)	
Solidago simplex	40.37 (22.3)		126.15 (88.16)		10.09 (6.92)	
Symphyotrichum porteri	0.00 (0.00)		5.05 (5.05)		0.00 (0.00)	
Taraxacum officinale	10.09 (6.92)		25.23 (16.10)		30.28 (12.72)	
Total	**100.92 (37.36)**	***b***	**625.69 (188.63)**	***a***	**650.92 (159.91)**	***a***
Perennial graminoid						
Carex rossii	10.09 (10.09)		30.28 (10.38)		146.33 (29.50)	
Muhlenbergia montana	5.05 (5.05)		35.32 (35.32)		312.85 (216.11)	
Total	**15.14 (11.01)**	***b***	**65.60 (35.07)**	***ab***	**459.18 (214.89)**	***a***

Taxa	Position: Center		Edge		Reference	
Shrub						
Ribes cereum	0.00 (0.00)		0.00 (0.00)		10.09 (6.92)	
Rubus idaeus	50.46 (45.40)		166.52 (109.47)		60.55 (35.22)	
Total	**50.46 (45.40)**	***a***	**166.52 (109.47)**	***a***	**70.64 (38.55)**	***a***
Tree						
Pinus contorta	0.00 (0.00)		5.05 (5.05)		0.00 (0.00)	
Total	**0.00 (0.00)**	***a***	**5.05 (5.05)**	***a***	**0.00 (0.00)**	***a***
Total vegetation	**297.71 (79.70)**	**b**	**1559.19 (288.55)**	**a**	**2235.34 (488.57)**	**a**

ANOVA results	Position effect: *Statistic*	*Probability*
Annual and biennial forb	7.13	**0.028**
Perennial forb	15.03	**<0.001**
Perennial grass	15.22	**<0.001**
Shrub	1.83	0.401
Tree	2.00	0.368
Total vegetation	20.86	**<0.001**

Table 5. Effect of slash pile burning on plant biomass within conifer forests of the Front Range of Colorado, USA. Plant biomass data was collected by position approximately 3 years post-burn (2010) from untreated fire scars during August. Mean values (g m^{-2}) (± 1 standard error) shown by position. Position effects were determined on untransformed data using the Cochran-Mantel-Haenszel statistic. Different letters indicate significant differences between positions at p=0.05 using Tukey's posthoc test on untransformed data. Species that could not be identified were analyzed in the total vegetation analysis but were removed during analysis of functional groups, accounting for any discrepancy between functional group totals and vegetation totals. Note: significant effect among positions for perennial forbs was not significant following multiple comparison posthoc tests.

	Position					
	Center		Edge		Reference	
			Number of germinates m^{-2}			
Annual and biennial forb						
Alyssum alyssoides	0.00 (0.00)		0.00 (0.00)		0.00 (0.00)	
Androsace septentrionalis	0.00 (0.00)		0.22 (0.22)		0.07 (0.07)	
Chenopodium album	0.00 (0.00)		0.00 (0.00)		0.00 (0.00)	
Chenopodium fremontii	3.22 (3.22)		1.33 (1.33)		0.00 (0.00)	
Chenopodium leptophyllum	0.75 (0.52)		0.76 (0.67)		0.00 (0.00)	
Cirsium vulgare	*0.00 (0.00)*		*28.38 (28.19)*		*0.00 (0.00)*	
Conyza canadensis	0.00 (0.00)		0.00 (0.00)		0.00 (0.00)	
Descurainia sophia	0.00 (0.00)		0.00 (0.00)		0.00 (0.00)	
Gayophytum diffusum	0.06 (0.06)		0.11 (0.11)		0.03 (0.02)	
Helianthus annuus	0.00 (0.00)		0.00 (0.00)		0.00 (0.00)	
Lactuca serriola	0.00 (0.00)		0.00 (0.00)		0.00 (0.00)	
Sisymbrium altissimum	0.00 (0.00)		0.49 (0.49)		0.00 (0.00)	
Verbascum thapsus	*0.00 (0.00)*		*0.00 (0.00)*		*0.00 (0.00)*	
Total	**4.03 (3.55)**	***a***	**31.30 (28.08)**	***a***	**0.09 (0.09)**	***a***
Annual grass						
Bromus tectorum	*1.06 (1.06)*		*0.01 (0.01)*		*0.14 (0.14)*	
Total	**1.06 (1.06)**	***a***	**0.01 (0.01)**	***a***	**0.14 (0.14)**	***a***
Perennial forb						
Achillea millefolium	0.48 (0.46)		0.10 (0.06)		0.55 (0.35)	
Allium cernuum	0.00 (0.00)		0.00 (0.00)		0.00 (0.00)	
Antennaria parvifolia	0.00 (0.00)		0.14 (0.14)		0.05 (0.04)	
Apocynum androsaemifolium	0.00 (0.00)		0.00 (0.00)		0.00 (0.00)	
Arabis glabra	0.00 (0.00)		0.05 (0.05)		0.30 (0.30)	
Arnica cordifolia	0.00 (0.00)		0.00 (0.00)		0.00 (0.00)	

	Position		
	Center	Edge	Reference
Perennial forb (con't)			
Artemisia campestris	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
Artemisia frigida	6.23 (6.19)	0.00 (0.00)	0.00 (0.00)
Artemisia ludoviciana	0.14 (0.10)	2.53 (2.53)	1.32 (0.76)
Asclepias speciosa	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
Astragalus flexuosus	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
Campanula rotundifolia	0.01 (0.01)	0.00 (0.00)	0.00 (0.00)
Carduus nutans	*0.00 (0.00)*	*0.00 (0.00)*	*0.00 (0.00)*
Centaurea diffusa	*0.00 (0.00)*	*0.00 (0.00)*	*0.00 (0.00)*
Chamerion angustifolium	0.32 (0.32)	0.25 (0.25)	0.01 (0.01)
Cirsium arvense	*0.00 (0.00)*	*0.01 (0.01)*	*0.59 (0.59)*
Epilobium ciliatum	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
Erigeron compositus	0.00 (0.00)	0.00 (0.00)	0.38 (0.38)
Eriogonum umbellatum	0.00 (0.00)	0.00 (0.00)	0.12 (0.12)
Erysimum capitatum	0.05 (0.05)	0.02 (0.02)	0.13 (0.13)
Fragaria virginiana	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
Gaillardia aristata	0.00 (0.00)	0.00 (0.00)	0.07 (0.05)
Grindelia squarrosa	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
Harbouria trachypleura	0.00 (0.00)	0.01 (0.01)	0.06 (0.06)
Heterotheca villosa	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
Lesquerella montana	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
Lomatium dissectum	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
Lupinus argenteus	0.00 (0.00)	0.04 (0.04)	0.17 (0.17)
Packera fendleri	0.00 (0.00)	0.00 (0.00)	0.04 (0.04)
Penstemon secundiflorus	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
Penstemon virens	0.00 (0.00)	0.11 (0.11)	0.40 (0.31)
Phacelia heterophylla	0.00 (0.00)	0.24 (0.24)	0.00 (0.00)
Phacelia sericea	0.00 (0.00)	4.03 (4.03)	9.02 (8.61)
Potentilla fissa	0.00 (0.00)	1.30 (1.30)	1.44 (1.11)
Sedum lanceolatum	0.00 (0.00)	0.00 (0.00)	0.20 (0.14)
Senecio eremophilus	0.04 (0.04)	0.00 (0.00)	4.68 (4.64)
Solidago simplex	0.07 (0.07)	0.03 (0.02)	1.10 (0.74)
Symphyotrichum porteri	0.00 (0.00)	0.01 (0.01)	0.05 (0.05)
Thermopsis divaricarpa	0.00 (0.00)	0.35 (0.24)	1.33 (1.01)
Total	**7.35 (6.18)** ***a***	**9.21 (4.69)** ***a***	**22.02 (13.03)** ***a***
Perennial grass			
Achnatherum nelsonii	0.22 (0.22)	0.00 (0.00)	0.00 (0.00)
Agrostis scabra	3.32 (2.28)	1.68 (1.68)	2.09 (2.00)

	Position					
	Center		Edge		Reference	
Perennial grass (con't)						
Bouteloua gracilis	0.00 (0.00)		0.00 (0.00)		0.00 (0.00)	
Bromus porteri	0.00 (0.00)		0.23 (0.23)		0.00 (0.00)	
Carex rossii	1.06 (0.68)		5.48 (2.77)		3.50 (1.62)	
Danthonia spicata	0.00 (0.00)		0.00 (0.00)		1.84 (1.84)	
Elymus elymoides	0.00 (0.00)		0.00 (0.00)		0.00 (0.00)	
Elymus lanceolatus	0.00 (0.00)		0.00 (0.00)		0.00 (0.00)	
Elymus trachycaulus	0.23 (0.23)		0.05 (0.05)		0.00 (0.00)	
Festuca arizonica	0.00 (0.00)		0.00 (0.00)		0.00 (0.00)	
Koeleria macrantha	0.00 (0.00)		0.00 (0.00)		0.18 (0.18)	
Leucopoa kingii	0.00 (0.00)		0.00 (0.00)		2.80 (2.74)	
Muhlenbergia montana	0.00 (0.00)		0.00 (0.00)		0.00 (0.00)	
Pascopyrum smithii	0.04 (0.04)		0.00 (0.00)		0.00 (0.00)	
Poa compressa	0.00 (0.00)		0.00 (0.00)		0.03 (0.03)	
Poa fendleriana	0.00 (0.00)		0.00 (0.00)		0.06 (0.06)	
Trisetum spicatum	0.00 (0.00)		0.00 (0.00)		0.00 (0.00)	
Total	**4.87 (2.52)**	***a***	**7.44 (4.08)**	***a***	**10.48 (4.28)**	***a***
Shrub						
Ceanothus velutinus	0.00 (0.00)		0.00 (0.00)		0.00 (0.00)	
Juniperus communis	0.00 (0.00)		0.00 (0.00)		22.32 (15.92)	
Mahonia repens	0.00 (0.00)		0.00 (0.00)		0.00 (0.00)	
Purshia tridentata	0.00 (0.00)		0.00 (0.00)		2.97 (2.49)	
Ribes cereum	0.00 (0.00)		0.97 (0.97)		0.26 (0.26)	
Rosa woodsii	0.00 (0.00)		0.22 (0.22)		0.00 (0.00)	
Rubus idaeus	0.85 (0.85)		0.55 (0.51)		0.00 (0.00)	
Total	**0.85 (0.85)**	***a***	**1.75 (1.07)**	***a***	**25.56 (18.29)**	***a***
Tree						
Pinus contorta	0.06 (0.04)		0.00 (0.00)		0.58 (0.58)	
Pinus ponderosa	0.00 (0.00)		0.00 (0.00)		0.00 (0.00)	
Populus tremuloides	0.00 (0.00)		0.00 (0.00)		0.00 (0.00)	
Pseudotsuga menziesii	0.00 (0.00)		0.00 (0.00)		1.60 (1.60)	
Total	**0.06 (0.04)**	***a***	**0.00 (0.00)**	***a***	**2.18 (1.67)**	***a***
Total vegetation	**18.22 (9.89)**	**b**	**49.71 (27.89)**	**ab**	**60.46 (22.60)**	**a**

Table 5 con't.

	Position effect	
ANOVA results	*Statistic*	*Probability*
Annual and biennial forb	3.52	0.172
Annual grass	0.29	0.867
Perennial forb	6.42	**0.040**
Perennial grass	4.75	0.093
Shrub	4.00	0.135
Tree	2.60	0.273
Total vegetation	3.83	**0.031**

Two years post-burn scars were dominated by bareground (70%) while unburned reference areas contained an average of only 5% bareground ($p<0.001$, Appendix 1). The lack of bareground in reference areas seem to be filled with forest litter, which was much more prevalent in reference areas than in scar centers (62% and 18% respectively). Vegetation cover results were similar to plant biomass results (Appendix 1).

3.2. Effects of seeding and surface manipulation treatments

Water infiltration was measured at the soil surface (0 cm) and at 2 cm and 4 cm below the soil surface (Table 6). As compared to untreated, control scars, fire scar centers showed increased infiltration at the soil surface, no significant difference at 2 cm, and decreased infiltration rates at 4 cm. Rehabilitation treatments did not influence water infiltration at 2 cm or 4 cm soil depth. However, woodchip much at the soil surface decreased infiltration in scar centers and edges as compared to untreated, control scars (Table 6).

Rehabilitation treatments had no effect on total soil carbon, total soil nitrogen, or soil carbon to nitrogen ratio ($p=0.801$, 0.393, 0.584, respectively) (data not presented).

Inorganic nitrogen, as measured using ion exchange resin bags indicated decreased plant available nitrogen during summer months in the branch and woodchip mulch treatments in scar centers as compared to untreated control scars (treatment main effects $p<0.001$; $p<0.001$, respectively, Table 7). This effect was present for both years of this study (2010 and 2011). Neither seeding nor scarification of soil had any effect on availability of inorganic nitrogen.

Rehabilitation treatments significantly affected soil moisture during June and September of 2011. Spring and fall measurements indicated increased soil moisture beneath woodchip

Table 6. Effect of fire scar restoration treatments on water infiltration within conifer forests of the Front Range of Colorado, USA. Soil infiltration was measured at all scars 2 years post-treatment and 4 years post-burn (September 2011). Mean values (± 1 standard error) for volume lost (mL min^{-1}) shown by depth, surface manipulation, and Position. Lowercase letters following standard errors indicate significant differences within a position. Non-parametric tests were used for all data except 'depth 0, center' where the power 3rd transformation was used to approximate normality. All differences significant at the p=0.05 level as indicated by the Cochran-Mantel-Haenszel statistic. ANOVA results for water infiltration shown below means table. Bold indicates a significant treatment or position effect, or a significant interaction between the two. Note: significant interaction effect in scar center at 4 cm depth was not significant following multiple comparison posthoc tests. Water infiltration means (± 1 standard error) for reference conditions available in the last column of this table (no statistical analysis run on this data).

Depth	Surface Manipulation	Position: Center		Position: Edge		Reference
		mL min^{-1}				
0 cm (Soil Surface)	Branches	6.09 (0.93)	*ab*	3.38 (0.65)	*bc*	
	Chips	3.97 (0.70)	*b*	2.09 (0.31)	*c*	
	Control	9.22 (1.30)	*a*	5.94 (0.90)	*a*	2.75 (0.27)
	Scarify	7.45 (0.72)	*a*	4.32 (0.51)	*ab*	
2 cm	Branches	3.63 (0.86)	*a*	3.00 (0.43)	*a*	
	Chips	2.97 (0.67)	*a*	2.59 (0.43)	*a*	
	Control	1.75 (0.33)	*a*	2.75 (0.49)	*a*	3.10 (0.30)
	Scarify	2.06 (0.42)	*a*	2.94 (0.37)	*a*	
4 cm	Branches	1.94 (0.97)	*a*	3.22 (0.61)	*a*	
	Chips	2.72 (0.50)	*a*	3.22 (0.59)	*a*	
	Control	1.61 (0.41)	*a*	3.44 (0.50)	*a*	3.42 (0.30)
	Scarify	2.35 (0.44)	*a*	4.82 (0.85)	*a*	

ANOVA results		Depth: 0 cm		Depth: 2 cm		Depth: 4 cm	
Position	*Test*	*Statistic*	*Probability*	*Statistic*	*Probability*	*Statistic*	*Probability*
Center	Treatment effect	6.84	**<0.001**	6.23	0.101	11.24	**0.011**
	Seeding effect	0.71	0.401	0.14	0.704	0.48	0.487
	Treatment x seeding	0.49	0.693	8.73	0.273	15.29	**0.033**
Edge	Treatment effect	17.66	**<0.001**	1.88	0.597	2.76	0.431
	Seeding effect	0.14	0.709	0.01	0.940	2.09	0.148
	Treatment x seeding	19.87	**0.006**	4.98	0.662	5.81	0.562

Table 7. Effect of fire scar restoration treatments on inorganic nitrogen within conifer forests of the Front Range of Colorado, USA. Inorganic nitrogen (mg N bag^{-1}) was measured using ion exchange resin bags at 8 sites over the summer months (June-September) of 2010 and 2011. Mean values (± 1 standard error) for total nitrogen sorption (NH4+NO3) shown by year, surface manipulation, and position. Lowercase letters following standard errors indicate significant differences between treatments and within a position and year. Natural log transformation was used to approximate normality, all differences significant at the p=0.05 level as indicated by Tukey's posthoc test following a significant ANOVA test. ANOVA results for inorganic nitrogen shown below means table. Bold indicates a significant treatment or position effect, or a significant interaction between the two. Inorganic nitrogen means (± 1 standard error) for reference conditions available in the last row of this table (no statistical analysis run on this data).

Position	Surface Manipulation	Summer Sampling Year 2010		2011	
		mg N bag^{-1}			
Center	Branches	19.98 (5.34)	*b*	3.11 (0.88)	*b*
	Chips	2.00 (0.96)	*c*	0.32 (0.16)	*c*
	Control	29.50 (4.68)	*a*	10.32 (2.31)	*a*
	Scarify	15.08 (2.58)	*ab*		*a*
Edge	Branches	5.38 (1.28)	*a*	3.41 (0.80)	*b*
	Chips	0.48 (0.17)	*b*	0.57 (0.16)	*c*
	Control	5.20 (1.12)	*a*	7.88 (1.40)	*a*
	Scarify	4.57 (1.30)	*a*	5.85 (1.33)	*ab*
Reference	All	4.42 (0.74)		9.11 (1.37)	

ANOVA results		Summer Sampling Year 2010		2011	
Position	*Test*	*Statistic*	*Probability*	*Statistic*	*Probability*
Center	Treatment effect	34.91	**<0.001**	31.58	**<0.001**
	Seeding effect	0.75	0.387	0.03	0.860
	Treatment x seeding	0.54	0.653	0.11	0.951
Edge	Treatment effect	10.15	**<0.001**	20.94	**<0.001**
	Seeding effect	0.14	0.709	0.07	0.795
	Treatment x seeding	1.09	0.355	0.14	0.938

mulch in scar centers as compared to untreated, control scars (treatment main effects $p<0.001$, $p<0.001$, respectively; Table 8).

Scar centers treated with woodchip mulch contained significantly less plant cover (Figure 5) than untreated control scars. However, neither branches added to scars nor scarifying soils resulted in significant differences in plant cover as compared to untreated control scars 2 years post-treatment (2011). Seeding scars also had no effect of plant cover.

Adding woodchip mulch to fire scars drastically reduced plant biomass in scar centers during both years of this study. While neither branches nor scarification altered biomass abundance (Table 9), seeding scar centers increased total biomass as compared to untreated control scars (seeding main effect $p<0.001$; Table 10). Seeding scars increased perennial forb species within scar centers but no other restoration treatments altered vegetation composition.

Reference areas typically contained kinnikinnick (*Arctostaphylos uva-ursi*), common juniper (*Juniperus communis*), and sedge species (*Carex sp.*) while the most common species in unseeded scars was fireweed (*Chamerion angustifolium*) during the first year of the study (2010). Additional volunteer species found in unseeded scars included prairie sagewort (*Artemisia frigida*), sedge species (*Carex sp.*), and cheatgrass (*Bromus tectorum*). The seeded species that produced the most biomass during the study were varileaf phacelia (*Phacelia heterophylla*), Front Range beardtongue (*Penstemon virens*), slender wheatgrass (*Elymus trachycaulus*), and sulphur-flower buckwheat (*Eriogonum umbellatum*) (Table 10).

Table 8. Effect of fire scar restoration treatments on soil moisture within conifer forests of the Front Range of Colorado, USA. Volumetric soil moisture (%) was measured at all sites during the spring and fall 2010 (year 1) and 2011 (year 2). Mean values (± 1 standard error) for soil moisture shown by year, surface manipulation, and position. Lowercase letters following standard errors indicate significant differences within a position. Data from center positions measured year 1 (spring) were natural log transformed; edge positions for the same time frame were square root transformed to approximate normality. Year 1 (fall) data was analyzed using non-parametric tests. Year 2 data was power 3^{rd} transformed to approximate normality. All differences significant at the p=0.05 level as indicated by Tukey's posthoc or the Cochran-Mantel-Haenszel statistic following a significant ANOVA test. ANOVA results for soil moisture shown below means table. Bold indicates a significant treatment or position effect, or a significant interaction between the two. Soil moisture means (± 1 standard error) for reference conditions available in the last column of this table (no statistical analysis run on this data).

Season	Surface Manipulation	Position				Reference
		Center		Edge		
		Percent				
June 2010	Branches	11.58 (0.52)	*b*	12.05 (0.52)	*b*	11.95 (0.28)
	Chips	15.97 (0.52)	*a*	14.81 (0.47)	*a*	
	Control	10.26 (0.38)	*c*	11.95 (0.58)	*b*	
	Scarify	10.77 (0.60)	*bc*	11.61 (0.58)	*b*	
September 2010	Branches	6.25 (0.27)	*b*	5.73 (0.16)	*b*	5.80 (0.07))
	Chips	9.96 (0.52)	*a*	7.05 (0.35)	*a*	
	Control	6.22 (0.22)	*b*	5.78 (0.16)	*b*	
	Scarify	6.07 (0.22)	*b*	5.88 (0.17)	*b*	
June 2011	Branches	16.66 (0.54)	*b*	17.05 (0.50)	*b*	17.50 (0.26)
	Chips	19.64 (0.60)	*a*	18.52 (0.52)	*a*	
	Control	16.26 (0.62)	*b*	17.43 (0.60)	*ab*	
	Scarify	16.03 (0.66)	*b*	17.00 (0.64)	*b*	
September 2011	Branches	11.54 (0.49)	*b*	11.11 (0.33)	*a*	10.13 (0.15)
	Chips	13.91 (0.66)	*a*	11.11 (0.37)	*a*	
	Control	10.68 (0.38)	*b*	11.17 (0.33)	*a*	
	Scarify	11.55 (0.49)	*b*	11.09 (0.30)	*a*	

Table 8 Continued.

ANOVA results		2010 June		2010 September		2011 June		2011 September	
		Statistic	*Probability*	*Statistic*	*Probability*	*Statistic*	*Probability*	*Statistic*	*Probability*
Center	Treatment effect	68.87	**<0.001**	61.42	**<0.001**	18.87	**<0.001**	12.44	**<0.001**
	Seed effect	0.35	0.553	2.29	0.130	4.90	**0.023**	0.00	0.974
	Treatment x seed	0.03	0.992	66.28	**<0.001**	0.18	0.907	2.38	0.073
Edge	Treatment effect	37.89	**<0.001**	23.51	**<0.001**	4.62	**0.004**	0.03	0.991
	Seed effect	0.03	0.870	0.842	0.359	0.06	0.805	5.65	**0.019**
	Treatment x seed	1.28	0.286	27.10	**<0.001**	0.78	0.507	0.53	0.660

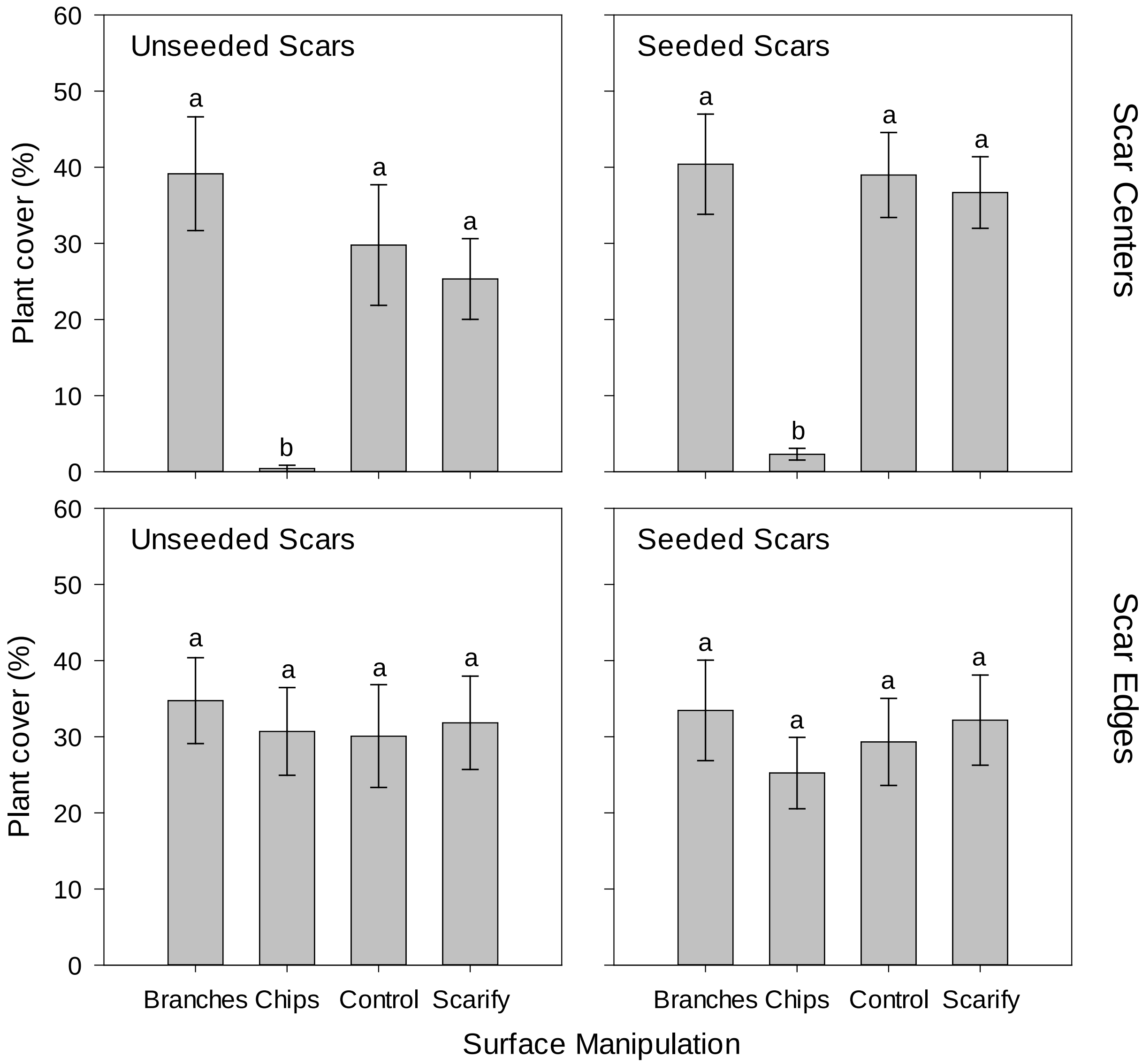

Figure 5. Effect of fire scar restoration treatments on vegetation cover within conifer forests of the Front Range of Colorado, USA. Data presented shows percent vegetation cover measured at all sites during the second year of this study (August 2011). Treatment effects were determined on untransformed data using the Cochran-Mantel-Haenszel statistic in SAS. Letters indicate significant differences by position using Tukey's posthoc test on untransformed data at the p=0.05 level, error bars are ± 1 standard error.

Table 9. Effect of fire scar restoration treatments (no seed additions) on plant biomass data collected during the second year of the study (August 2011) in scar centers broken out by functional groups within conifer forests of the Front Range of Colorado, USA. Mean values (g m^{-2}) (± 1 standard error) shown with letters signifying differences within a position using Cochran-Mantel-Haenszel test on untransformed data. Data was non-normal, all functional groups were tested using Friedman's non-parametric test. ANOVA results for plant biomass shown below means tables. Bold indicates a significant treatment or position effect, or a significant interaction between the two. Note: Some tests were significant at the 0.05 level, but posthoc multiple comparisons tests showed no significant difference between means. Functional groups are indicated in bold, seeded species are underlined, and noxious species are indicated in italics. Species that could not be identified were analyzed in the total vegetation analysis but were removed during analysis of functional groups, accounting for any discrepancy between functional group totals and vegetation totals. Plant biomass means (± 1 standard error) for reference conditions available in the last column of this table (no statistical analysis run on this data).

	Not Seeded								Reference
Taxa	Branches		Chips		Control		Scarify		Conditions
					g m^{-2}				
Annual and biennial forb									
Alyssum alyssoides	0.00 (0.00)		0.00 (0.00)		0.00 (0.00)		0.06 (0.06)		0.01 (0.01)
Androsace septentrionalis	0.00 (0.00)		0.00 (0.00)		0.00 (0.00)		0.00 (0.00)		0.01 (0.01)
Chenopodium album	0.00 (0.00)		0.00 (0.00)		0.00 (0.00)		0.00 (0.00)		0.00 (0.00)
<u>Chenopodium fremontii</u>	0.53 (0.53)		0.00 (0.00)		0.00 (0.00)		0.00 (0.00)		0.15 (0.08)
<u>Chenopodium leptophyllum</u>	0.00 (0.00)		0.00 (0.00)		0.03 (0.03)		0.03 (0.03)		0.20 (0.07)
Cirsium vulgare	*0.00 (0.00)*		*0.00 (0.00)*		*0.00 (0.00)*		*0.00 (0.00)*		*0.02 (0.02)*
Conyza canadensis	0.00 (0.00)		0.00 (0.00)		0.00 (0.00)		0.51 (0.51)		0.06 (0.06)
Descurainia sophia	0.55 (0.55)		0.00 (0.00)		0.00 (0.00)		0.00 (0.00)		0.07 (0.07)
Gayophytum diffusum	1.27 (0.77)		0.00 (0.00)		0.57 (0.48)		0.41 (0.32)		0.39 (0.14)
Helianthus annuus	0.00 (0.00)		0.00 (0.00)		0.00 (0.00)		0.00 (0.00)		0.01 (0.01)
Lactuca serriola	0.00 (0.00)		0.00 (0.00)		0.01 (0.01)		0.02 (0.02)		0.00 (0.00)
Sisymbrium altissimum	0.00 (0.00)		0.00 (0.00)		0.00 (0.00)		0.00 (0.00)		0.04 (0.04)
Verbascum thapsus	*0.00 (0.00)*		*0.00 (0.00)*		*0.05 (0.05)*		*0.00 (0.00)*		*0.02 (0.02)*
Total	**2.35 (1.27)**	***a***	**0.00 (0.00)**	***a***	**0.67 (0.48)**	***a***	**1.02 (0.58)**	***a***	**0.98 (0.24)**

Taxa	Not Seeded Branches		Chips		Control		Scarify		Reference Conditions
Annual grass									
Bromus tectorum	*0.53 (0.47)*		*0.00 (0.00)*		*0.44 (0.44)*		*0.58 (0.52)*		*0.45 (0.27)*
Total	**0.53 (0.47)**	***a***	**0.00 (0.00)**	***a***	**0.44 (0.44)**	***a***	**0.58 (0.52)**	***a***	**0.45 (0.27)**
Perennial forb									
Achillea millefolium	2.02 (1.01)		0.00 (0.00)		6.83 (4.76)		6.27 (3.54)		2.67 (0.84)
Allium cernuum	0.00 (0.00)		0.00 (0.00)		0.00 (0.00)		0.00 (0.00)		0.01 (0.00)
Antennaria parvifolia	0.00 (0.00)		0.00 (0.00)		0.00 (0.00)		0.00 (0.00)		0.01 (0.01)
Apocynum androsaemifolium	0.17 (0.17)		0.00 (0.00)		0.00 (0.00)		0.07 (0.07)		0.15 (0.12)
Arabis glabra	0.63 (0.63)		0.00 (0.00)		0.00 (0.00)		0.00 (0.00)		0.18 (0.13)
Arnica cordifolia	0.00 (0.00)		0.00 (0.00)		0.00 (0.00)		0.00 (0.00)		0.02 (0.02)
Artemisia campestris	0.13 (0.13)		0.00 (0.00)		0.70 (0.62)		0.05 (0.05)		0.35 (0.25)
Artemisia frigida	4.31 (2.97)		0.00 (0.00)		7.80 (7.69)		5.99 (4.00)		4.12 (1.38)
Artemisia ludoviciana	1.23 (1.23)		0.00 (0.00)		0.40 (0.29)		0.07 (0.07)		0.79 (0.21)
Asclepias speciosa	0.00 (0.00)		0.00 (0.00)		0.01 (0.01)		0.00 (0.00)		0.00 (0.00)
Astragalus flexuosus	0.00 (0.00)		0.00 (0.00)		0.00 (0.00)		0.00 (0.00)		0.02 (0.02)
Campanula rotundifolia	0.03 (0.03)		0.00 (0.00)		0.00 (0.00)		0.00 (0.00)		0.04 (0.02)
Carduus nutans	*0.00 (0.00)*		*0.00 (0.00)*		*0.00 (0.00)*		*0.00 (0.00)*		*0.51 (0.51)*
Centaurea diffusa	*0.00 (0.00)*		*0.00 (0.00)*		*0.00 (0.00)*		*0.00 (0.00)*		*0.04 (0.04)*
Chamerion angustifolium	4.13 (4.02)		0.00 (0.00)		0.38 (0.38)		0.00 (0.00)		0.79 (0.52)
Cirsium arvense	*0.14 (0.14)*		*0.00 (0.00)*		*0.57 (0.57)*		*6.38 (6.38)*		*1.27 (0.84)*
Epilobium ciliatum	1.12 (1.12)		0.00 (0.00)		0.00 (0.00)		0.00 (0.00)		0.15 (0.14)
Erigeron compositus	0.09 (0.09)		0.00 (0.00)		0.00 (0.00)		0.00 (0.00)		0.01 (0.01)
Eriogonum umbellatum	0.00 (0.00)		0.00 (0.00)		0.00 (0.00)		0.00 (0.00)		2.06 (0.45)
Erysimum capitatum	1.14 (0.98)		0.00 (0.00)		1.75 (1.18)		0.69 (0.69)		0.51 (0.22)
Fragaria virginiana	0.00 (0.00)		0.00 (0.00)		0.04 (0.04)		0.00 (0.00)		0.01 (0.01)

Taxa	Not Seeded: Branches		Chips		Control		Scarify		Reference Conditions
Perennial forb con't									
Gaillardia aristata	0.00 (0.00)		0.00 (0.00)		0.00 (0.00)		0.00 (0.00)		0.01 (0.00)
Grindelia squarrosa	0.00 (0.00)		0.00 (0.00)		0.00 (0.00)		0.00 (0.00)		0.06 (0.04)
Harbouria trachypleura	0.00 (0.00)		0.00 (0.00)		0.00 (0.00)		0.00 (0.00)		0.06 (0.01)
Heterotheca villosa	0.07 (0.06)		0.06 (0.05)		1.27 (0.72)		2.04 (1.89)		1.17 (0.36)
Lesquerella montana	0.00 (0.00)		0.00 (0.00)		0.00 (0.00)		0.00 (0.00)		0.00 (0.00)
Lomatium dissectum	0.00 (0.00)		0.00 (0.00)		0.00 (0.00)		0.00 (0.00)		0.01 (0.01)
Lupinus argenteus	0.00 (0.00)		0.00 (0.00)		1.53 (1.10)		1.08 (0.85)		0.96 (0.28)
Packera fendleri	0.53 (0.27)		0.00 (0.00)		0.00 (0.00)		1.88 (1.73)		0.31 (0.22)
Penstemon secundiflorus	0.00 (0.00)		0.00 (0.00)		0.00 (0.00)		0.00 (0.00)		0.05 (0.03)
Penstemon virens	0.07 (0.07)		0.00 (0.00)		0.23 (0.20)		3.92 (2.30)		1.45 (0.37)
Phacelia heterophylla	0.25 (0.25)		0.00 (0.00)		0.04 (0.04)		0.00 (0.00)		6.69 (1.66)
Phacelia sericea	0.00 (0.00)		0.00 (0.00)		0.26 (0.26)		0.69 (0.69)		0.39 (0.26)
Potentilla fissa	0.00 (0.00)		0.00 (0.00)		0.00 (0.00)		0.16 (0.16)		0.08 (0.03)
Sedum lanceolatum	0.02 (0.02)		0.00 (0.00)		0.00 (0.00)		0.00 (0.00)		0.01 (0.00)
Senecio eremophilus	0.24 (0.22)		0.06 (0.06)		1.47 (1.34)		3.38 (2.31)		0.75 (0.31)
Solidago simplex	0.47 (0.24)		0.04 (0.04)		0.48 (0.30)		0.24 (0.17)		0.28 (0.06)
Symphyotrichum porteri	0.00 (0.00)		0.00 (0.00)		0.00 (0.00)		0.00 (0.00)		0.11 (0.05)
Taraxacum officinale	0.05 (0.04)		0.00 (0.00)		0.00 (0.00)		0.00 (0.00)		0.01 (0.01)
Thermopsis divaricarpa	5.33 (5.33)		0.00 (0.00)		0.00 (0.00)		0.00 (0.00)		0.75 (0.67)
Total	**22.16 (7.07)**	***ab***	**0.18 (0.10)**	***b***	**23.77 (8.52)**	***ab***	**32.90 (9.12)**	***a***	**26.81 (3.01)**
Perennial grass									
Achnatherum nelsonii	0.00 (0.00)		0.00 (0.00)		0.31 (0.31)		0.00 (0.00)		0.04 (0.04)
Agrostis scabra	8.64 (5.30)		0.00 (0.00)		9.97 (6.33)		3.45 (1.99)		3.47 (1.10)
Bouteloua gracilis	0.10 (0.10)		0.00 (0.00)		0.00 (0.00)		0.00 (0.00)		0.03 (0.02)
Bromus porteri	0.82 (0.82)		0.00 (0.00)		1.71 (1.67)		0.00 (0.00)		0.32 (0.23)

Taxa	Not Seeded Branches		Chips		Control		Scarify		Reference Conditions
Perennial grass (con't)									
Carex rossii	2.02 (1.21)		0.00 (0.00)		3.07 (1.80)		7.36 (5.94)		2.52 (0.90)
<u>Danthonia spicata</u>	0.00 (0.00)		0.00 (0.00)		0.00 (0.00)		0.00 (0.00)		0.01 (0.01)
<u>Elymus elymoides</u>	0.00 (0.00)		0.00 (0.00)		0.00 (0.00)		0.21 (0.21)		0.15 (0.05)
<u>Elymus lanceolatus</u>	0.11 (0.11)		0.00 (0.00)		0.00 (0.00)		0.00 (0.00)		0.77 (0.29)
<u>Elymus trachycaulus</u>	4.89 (4.89)		0.00 (0.00)		0.00 (0.00)		2.51 (2.51)		4.69 (1.20)
<u>Festuca arizonica</u>	0.00 (0.00)		0.00 (0.00)		0.00 (0.00)		0.00 (0.00)		0.14 (0.09)
<u>Koeleria macrantha</u>	0.08 (0.05)		0.00 (0.00)		0.00 (0.00)		0.12 (0.12)		0.44 (0.13)
Leucopoa kingii	0.00 (0.00)		0.00 (0.00)		0.15 (0.15)		0.03 (0.03)		0.09 (0.06)
<u>Muhlenbergia montana</u>	0.00 (0.00)		0.00 (0.00)		0.00 (0.00)		0.00 (0.00)		0.40 (0.08)
<u>Pascopyrum smithii</u>	0.00 (0.00)		0.00 (0.00)		0.00 (0.00)		0.23 (0.23)		0.22 (0.15)
Poa compressa	0.00 (0.00)		0.00 (0.00)		0.00 (0.00)		0.00 (0.00)		0.00 (0.00)
<u>Poa fendleriana</u>	0.00 (0.00)		0.00 (0.00)		0.00 (0.00)		0.00 (0.00)		0.03 (0.01)
Trisetum spicatum	0.00 (0.00)		0.00 (0.00)		0.01 (0.01)		0.00 (0.00)		0.00 (0.00)
Total	**16.66 (7.73)**	***a***	**0.00 (0.00)**	***a***	**15.23 (6.88)**	***a***	**13.90 (7.59)**	***a***	**13.32 (2.00)**
Shrub									
Ceanothus velutinus	0.00 (0.00)		0.00 (0.00)		0.00 (0.00)		0.60 (0.60)		0.07 (0.07)
Juniperus communis	0.00 (0.00)		0.00 (0.00)		0.00 (0.00)		0.04 (0.04)		0.01 (0.01)
Mahonia repens	0.00 (0.00)		0.00 (0.00)		0.00 (0.00)		0.00 (0.00)		0.00 (0.00)
Purshia tridentata	0.00 (0.00)		0.00 (0.00)		0.00 (0.00)		0.12 (0.12)		0.01 (0.01)
<u>Ribes cereum</u>	0.00 (0.00)		0.00 (0.00)		0.00 (0.00)		0.00 (0.00)		0.02 (0.01)
<u>Rosa woodsii</u>	0.00 (0.00)		0.00 (0.00)		0.00 (0.00)		0.00 (0.00)		0.07 (0.02)
Rubus idaeus	0.00 (0.00)		0.00 (0.00)		0.57 (0.54)		0.14 (0.14)		0.10 (0.07)
Total	**0.00 (0.00)**	***a***	**0.00 (0.00)**	***a***	**0.57 (0.54)**	***a***	**0.90 (0.61)**	***a***	**0.29 (0.11)**

Taxa	Not Seeded: Branches		Chips		Control		Scarify		Reference Conditions
Tree									
Pinus contorta	0.03 (0.03)		0.00 (0.00)		0.29 (0.27)		0.02 (0.02)		0.07 (0.04)
Pinus ponderosa	0.00 (0.00)		0.00 (0.00)		0.00 (0.00)		0.00 (0.00)		0.01 (0.01)
Populus tremuloides	0.13 (0.13)		0.00 (0.00)		0.00 (0.00)		0.00 (0.00)		0.04 (0.03)
Pseudotsuga menziesii	0.09 (0.09)		0.00 (0.00)		0.00 (0.00)		0.01 (0.01)		0.01 (0.01)
Total	**0.25 (0.15)**	***a***	**0.00 (0.00)**	***a***	**0.29 (0.27)**	***a***	**0.04 (0.03)**	***a***	**0.13 (0.05)**
Total Vegetation	**42.17 (9.02)**	**a**	**0.18 (0.10)**	**b**	**41.16 (11.07)**	**a**	**49.43 (14.50)**	**a**	**42.08 (4.29)**

Table 9 con't.

ANOVA results		2010		2011	
Functional Group	*Test*	*Statistic*	*Probability*	*Statistic*	*Probability*
Annual and biennial forb	Treatment effect	16.68	**<0.001**	26.77	**<0.001**
	Seed effect	19.50	**<0.001**	9.84	**0.017**
	Treatment x seed	43.04	**<0.001**	41.50	**<0.001**
Annual grass	Treatment effect	0.69	0.875	3.07	0.381
	Seed effect	0.06	0.814	2.41	0.121
	Treatment x seed	3.44	0.841	8.71	0.274
Perennial forb	Treatment effect	35.35	**<0.001**	50.38	**<0.001**
	Seed effect	37.97	**<0.001**	14.05	**<0.001**
	Treatment x seed	75.79	**<0.001**	65.55	**<0.001**
Perennial grass	Treatment effect	20.03	**<0.001**	31.76	**<0.001**
	Seed effect	30.55	**<0.001**	23.48	**<0.001**
	Treatment x seed	55.54	**<0.001**	56.43	**<0.001**
Shrub	Treatment effect	6.48	0.090	8.68	**0.034**
	Seed effect	34.41	**<0.001**	9.67	**0.002**
	Treatment x seed	51.20	**<0.001**	28.04	**<0.001**
Tree	Treatment effect	1.60	0.659	0.85	0.838
	Seed effect	1.51	0.220	0.11	0.736
	Treatment x seed	11.58	0.115	5.87	0.555
Total vegetation	Treatment effect	38.30	**<0.001**	64.58	**<0.001**
	Seed effect	21.95	**<0.001**	7.43	**0.006**
	Treatment x seed	62.16	**<0.001**	72.72	**<0.001**

Table 10. Effect of fire scar restoration treatments (with seed additions) on plant biomass data collected during the second year of the study (August 2011) in scar centers broken out by functional groups within conifer forests of the Front Range of Colorado, USA. Mean values (g m^{-2}) (± 1 standard error) shown with letters signifying differences within a position using Cochran-Mantel-Haenszel test on untransformed data. Data was non-normal, all functional groups were tested using Friedman's non-parametric test. ANOVA results for plant biomass shown below Table 9. Bold indicates a significant treatment or position effect, or a significant interaction between the two. Note: Some tests were significant at the 0.05 level, but posthoc multiple comparisons tests showed no significant difference between means. Functional groups are indicated in bold, seeded species are underlined, and noxious species are indicated in italics. Species that could not be identified were analyzed in the total vegetation analysis but were removed during analysis of functional groups, accounting for any discrepancy between functional group totals and vegetation totals.

	Seeded							
Taxa	Branches		Chips		Control		Scarify	
				g m⁻²				
Annual and biennial forb								
Alyssum alyssoides	0.00 (0.00)		0.00 (0.00)		0.00 (0.00)		0.00 (0.00)	
Androsace septentrionalis	0.00 (0.00)		0.00 (0.00)		0.07 (0.07)		0.00 (0.00)	
Chenopodium album	0.00 (0.00)		0.00 (0.00)		0.03 (0.03)		0.00 (0.00)	
<u>Chenopodium fremontii</u>	0.14 (0.10)		0.00 (0.00)		0.09 (0.03)		0.44 (0.33)	
<u>Chenopodium leptophyllum</u>	0.31 (0.12)		0.00 (0.00)		0.39 (0.15)		0.83 (0.55)	
Cirsium vulgare	*0.00 (0.00)*		*0.00 (0.00)*		*0.15 (0.15)*		*0.00 (0.00)*	
Conyza canadensis	0.00 (0.00)		0.00 (0.00)		0.00 (0.00)		0.00 (0.00)	
Descurainia sophia	0.00 (0.00)		0.00 (0.00)		0.00 (0.00)		0.00 (0.00)	
Gayophytum diffusum	0.12 (0.09)		0.00 (0.00)		0.08 (0.06)		0.64 (0.49)	
Helianthus annuus	0.00 (0.00)		0.00 (0.00)		0.00 (0.00)		0.06 (0.06)	
Lactuca serriola	0.00 (0.00)		0.00 (0.00)		0.00 (0.00)		0.00 (0.00)	
Sisymbrium altissimum	0.00 (0.00)		0.00 (0.00)		0.30 (0.30)		0.00 (0.00)	
Verbascum thapsus	*0.00 (0.00)*		*0.00 (0.00)*		*0.12 (0.12)*		*0.00 (0.00)*	
Total	**0.58 (0.18)**	***a***	**0.00 (0.00)**	***a***	**1.21 (0.48)**	***a***	**1.97 (1.04)**	***a***

Taxa	Seeded Branches		Chips		Control		Scarify	
Annual grass								
Bromus tectorum	*0.00 (0.00)*		*0.00 (0.00)*		*2.05 (2.05)*		*0.00 (0.00)*	
Total	**0.00 (0.00)**	***a***	**0.00 (0.00)**	***a***	**2.05 (2.05)**	***a***	**0.00 (0.00)**	***a***
Perennial forb								
Achillea millefolium	1.74 (1.42)		0.00 (0.00)		2.32 (2.05)		2.19 (1.67)	
Allium cernuum	0.00 (0.00)		0.06 (0.04)		0.00 (0.00)		0.00 (0.00)	
Antennaria parvifolia	0.00 (0.00)		0.00 (0.00)		0.09 (0.09)		0.00 (0.00)	
Apocynum androsaemifolium	0.00 (0.00)		0.93 (0.93)		0.00 (0.00)		0.00 (0.00)	
Arabis glabra	0.00 (0.00)		0.00 (0.00)		0.85 (0.85)		0.00 (0.00)	
Arnica cordifolia	0.00 (0.00)		0.00 (0.00)		0.14 (0.14)		0.00 (0.00)	
Artemisia campestris	0.00 (0.00)		0.00 (0.00)		0.00 (0.00)		1.90 (1.90)	
Artemisia frigida	4.93 (4.35)		0.00 (0.00)		6.99 (4.27)		2.93 (1.63)	
Artemisia ludoviciana	2.62 (0.78)		0.00 (0.00)		0.77 (0.27)		1.21 (0.52)	
Asclepias speciosa	0.00 (0.00)		0.00 (0.00)		0.00 (0.00)		0.00 (0.00)	
Astragalus flexuosus	0.00 (0.00)		0.00 (0.00)		0.00 (0.00)		0.12 (0.12)	
Campanula rotundifolia	0.21 (0.17)		0.00 (0.00)		0.00 (0.00)		0.05 (0.05)	
Carduus nutans	*4.07 (4.07)*		*0.00 (0.00)*		*0.00 (0.00)*		*0.00 (0.00)*	
Centaurea diffusa	*0.00 (0.00)*		*0.00 (0.00)*		*0.35 (0.35)*		*0.00 (0.00)*	
Chamerion angustifolium	0.60 (0.57)		0.05 (0.05)		1.12 (0.89)		0.00 (0.00)	
Cirsium arvense	*1.54 (1.54)*		*0.00 (0.00)*		*1.41 (1.41)*		*0.14 (0.14)*	
Epilobium ciliatum	0.00 (0.00)		0.00 (0.00)		0.00 (0.00)		0.04 (0.04)	
Erigeron compositus	0.00 (0.00)		0.00 (0.00)		0.00 (0.00)		0.00 (0.00)	
Eriogonum umbellatum	1.68 (0.59)		0.03 (0.03)		4.68 (1.41)		10.07 (2.46)	
Erysimum capitatum	0.45 (0.39)		0.00 (0.00)		0.01 (0.01)		0.00 (0.00)	
Fragaria virginiana	0.01 (0.01)		0.00 (0.00)		0.00 (0.00)		0.00 (0.00)	

Taxa	Seeded Branches		Chips		Control		Scarify	
Perennial forb (con't)								
Gaillardia aristata	0.01 (0.01)		0.00 (0.00)		0.00 (0.00)		0.03 (0.03)	
Grindelia squarrosa	0.28 (0.28)		0.00 (0.00)		0.14 (0.10)		0.07 (0.07)	
Harbouria trachypleura	0.13 (0.06)		0.11 (0.05)		0.02 (0.01)		0.19 (0.08)	
Heterotheca villosa	1.08 (0.40)		0.01 (0.01)		1.38 (0.41)		3.42 (1.89)	
Lesquerella montana	0.00 (0.00)		0.00 (0.00)		0.04 (0.04)		0.00 (0.00)	
Lomatium dissectum	0.00 (0.00)		0.07 (0.07)		0.01 (0.01)		0.00 (0.00)	
Lupinus argenteus	0.82 (0.66)		0.10 (0.05)		2.56 (1.59)		1.52 (0.43)	
Packera fendleri	0.06 (0.06)		0.00 (0.00)		0.00 (0.00)		0.02 (0.02)	
Penstemon secundiflorus	0.14 (0.10)		0.00 (0.00)		0.00 (0.00)		0.25 (0.25)	
Penstemon virens	1.81 (0.73)		0.00 (0.00)		1.97 (0.50)		3.61 (1.47)	
Phacelia heterophylla	21.85 (9.80)		0.14 (0.14)		13.86 (4.09)		17.38 (6.21)	
Phacelia sericea	1.91 (1.90)		0.00 (0.00)		0.21 (0.21)		0.04 (0.03)	
Potentilla fissa	0.26 (0.12)		0.00 (0.00)		0.15 (0.06)		0.06 (0.04)	
Sedum lanceolatum	0.05 (0.03)		0.00 (0.00)		0.00 (0.00)		0.00 (0.00)	
Senecio eremophilus	0.29 (0.27)		0.00 (0.00)		0.01 (0.01)		0.52 (0.48)	
Solidago simplex	0.61 (0.22)		0.00 (0.00)		0.21 (0.07)		0.16 (0.07)	
Symphyotrichum porteri	0.30 (0.26)		0.00 (0.00)		0.21 (0.21)		0.39 (0.23)	
Taraxacum officinale	0.04 (0.04)		0.00 (0.00)		0.00 (0.00)		0.00 (0.00)	
Thermopsis divaricarpa	0.06 (0.06)		0.47 (0.21)		0.01 (0.01)		0.10 (0.10)	
Total	**47.56 (13.06)**	***a***	**1.99 (1.18)**	***b***	**39.54 (6.81)**	***a***	**46.41 (7.18)**	***a***
Perennial grass								
Achnatherum nelsonii	0.00 (0.00)		0.00 (0.00)		0.00 (0.00)		0.00 (0.00)	
Agrostis scabra	1.95 (1.28)		0.00 (0.00)		2.24 (1.13)		1.53 (1.07)	
Bouteloua gracilis	0.13 (0.10)		0.00 (0.00)		0.00 (0.00)		0.00 (0.00)	
Bromus porteri	0.00 (0.00)		0.00 (0.00)		0.00 (0.00)		0.00 (0.00)	

Taxa	Seeded							
	Branches		Chips		Control		Scarify	
Perennial grass (con't)								
Carex rossii	1.12 (0.69)		0.09 (0.06)		1.52 (1.38)		4.94 (2.96)	
Danthonia spicata	0.02 (0.02)		0.02 (0.02)		0.05 (0.05)		0.03 (0.03)	
Elymus elymoides	0.05 (0.03)		0.00 (0.00)		0.20 (0.13)		0.77 (0.33)	
Elymus lanceolatus	0.02 (0.02)		0.54 (0.35)		1.36 (0.88)		4.11 (1.99)	
Elymus trachycaulus	15.34 (5.60)		0.61 (0.28)		4.60 (1.86)		9.57 (4.46)	
Festuca arizonica	1.00 (0.73)		0.00 (0.00)		0.11 (0.08)		0.00 (0.00)	
Koeleria macrantha	0.71 (0.35)		0.18 (0.18)		1.55 (0.86)		0.87 (0.37)	
Leucopoa kingii	0.45 (0.45)		0.00 (0.00)		0.12 (0.12)		0.00 (0.00)	
Muhlenbergia montana	0.91 (0.33)		0.00 (0.00)		1.50 (0.35)		0.78 (0.32)	
Pascopyrum smithii	0.06 (0.06)		0.26 (0.30)		0.06 (0.06)		1.17 (1.17)	
Poa compressa	0.00 (0.00)		0.00 (0.00)		0.04 (0.04)		0.00 (0.00)	
Poa fendleriana	0.10 (0.08)		0.06 (0.04)		0.02 (0.02)		0.03 (0.03)	
Trisetum spicatum	0.00 (0.00)		0.00 (0.00)		0.00 (0.00)		0.00 (0.00)	
Total	**21.86 (5.69)**	***ab***	**1.75 (0.58)**	***b***	**13.38 (3.01)**	***ab***	**23.82 (5.80)**	***a***
Shrub								
Ceanothus velutinus	0.00 (0.00)		0.00 (0.00)		0.00 (0.00)		0.00 (0.00)	
Juniperus communis	0.00 (0.00)		0.00 (0.00)		0.00 (0.00)		0.00 (0.00)	
Mahonia repens	0.00 (0.00)		0.00 (0.00)		0.00 (0.00)		0.01 (0.01)	
Purshia tridentata	0.00 (0.00)		0.00 (0.00)		0.00 (0.00)		0.00 (0.00)	
Ribes cereum	0.10 (0.06)		0.00 (0.00)		0.00 (0.00)		0.03 (0.03)	
Rosa woodsii	0.27 (0.13)		0.11 (0.05)		0.01 (0.01)		0.20 (0.08)	
Rubus idaeus	0.00 (0.00)		0.00 (0.00)		0.00 (0.00)		0.13 (0.13)	
Total	**0.37 (0.16)**	***a***	**0.11 (0.05)**	***a***	**0.01 (0.01)**	***a***	**0.37 (0.17)**	***a***

Taxa	Seeded							
	Branches		Chips		Control		Scarify	
Tree								
Pinus contorta	0.05 (0.03)		0.02 (0.02)		0.01 (0.01)		0.11 (0.07)	
Pinus ponderosa	0.00 (0.00)		0.10 (0.10)		0.00 (0.00)		0.00 (0.00)	
Populus tremuloides	0.00 (0.00)		0.20 (0.20)		0.00 (0.00)		0.00 (0.00)	
Pseudotsuga menziesii	0.00 (0.00)		0.00 (0.00)		0.00 (0.00)		0.00 (0.00)	
Total	**0.05 (0.03)**	***a***	**0.32 (0.22)**	***a***	**0.01 (0.01)**	***a***	**0.11 (0.07)**	***a***
Total Vegetation	**70.71 (17.07)**	**a**	**4.16 (1.28)**	**b**	**56.20 (9.44)**	**a**	**72.68 (12.27)**	**a**

4. DISCUSSION

Despite the widespread use of slash pile burning as a management tool, many managers lack information regarding whether rehabilitation treatments are necessary on resulting fire scars and if so, which techniques are most effective. In this study, the alteration of physical and chemical soil properties was found to have little impact on vegetation recovery of fire scars. Within fire scars along the Front Range of Colorado, availability of plant propagules appears to be the main limiting factor to recovery.

Others (Esquilin *et al.,* 2007; Meyer, 2009; Creech *et al.,* 2012) have found that pile burning can increase soil temperatures to lethal levels for plant propagules. My results support these findings; seed density in soils taken from fire scar centers was greatly diminished relative to scar edges and reference areas. Additionally, I observed the presence of hydrophobic layers, a significant pulse of inorganic nitrogen, and altered soil physical properties following slash pile burning.

Evidence from testing water infiltration confirms that a hydrophobic layer was produced during pile burning. However, my findings suggest repellency was not a limiting factor to vegetation recovery 4 years post-burn. Water repellency was detected in soils beneath fire scars at 2 cm and 4 cm during the third year of the study; however, year four results, regardless of surface manipulation, show no difference in water infiltration at 2 cm or at 4 cm indicating this layer was no longer present. This suggests, as others have noted (DeBano, 1981), that water repellant layers degrade with time.

Surface manipulation treatments were effective at mitigating only some of the negative soil physical and chemical properties measured during this study. Woodchip mulch had the greatest impact on altering soils within fire scars. As observed in other studies (Miller and Seastedt, 2009; Fornwalt and Rhoades, 2011), woodchip mulch added to the soil surface decreased the pulse of inorganic nitrogen produced following pile burning. Due to the short duration of this study it is difficult to predict how long this effect will last, though other studies (Miller and Seastedt, 2009; Rhoades *et al.*, 2012) have shown that minimizing the inorganic nitrogen pulse using woodchip mulch tends to be a relatively short lived effect. However, as Rhoades *et al.* (2012) observed, the pulse of inorganic nitrogen itself may be relatively short-lived and a short-term management technique such as the application of woodchips may be sufficient to reduce excess nitrogen into the ecosystem. Even short-lived reduction of excess nitrogen may be beneficial in certain ecosystems, especially near streams or where municipal water supplies originate. I also noticed a decrease in water infiltration at the soil surface beneath woodchip mulch in scar centers. This may be attributed to the increased soil moisture consistently found beneath woodchip mulch as the infiltration method used is highly dependent upon initial soil moisture. This method causes water to infiltrate more slowly into the soil when the soil is saturated. Similar to the woodchip mulch addition, slash branches added to fire scars decreased inorganic soil nitrogen; however, this treatment had no effect on any other soil property. Scarification of soils within fire scars also had no significant impact on soil properties in this study.

As hypothesized, seeding fire scars significantly increased vegetation abundance overall. I observed significantly greater total plant biomass in seeded scar centers as compared to untreated control scars. Seeded scar centers contained a greater abundance of perennial forb species than unseeded scar centers; however, seeded scar centers contained no other significant differences in plant community composition. As a large proportion of the seed mix contained perennial forb species, it stands to reason that seeding had a direct impact on vegetation recovery in slash pile scars.

As other studies have shown (Miller and Seastedt, 2009; Wolk and Rocca, 2009) woodchip mulch added to the soil surface inhibited vegetation growth almost completely. While scarification and slash branch addition did not hinder vegetation growth, no differences in vegetation between these treatments and the untreated controls were observed.

Two noxious species were observed in soil seedbank samples: Canada thistle (*Cirsium arvense*) and common mullein (*Verbascum thapsus*), and six noxious species were observed growing in scars during the duration of the study: cheatgrass, nodding plumeless thistle (*Carduus nutans*), diffuse knapweed (*Centaurea diffusa*), Canada thistle, bull thistle (*Cirsium vulgare*), and common mullein. In the short term, neither surface manipulations nor seeding scars made any difference in the abundance of noxious species found in scar centers.

Slash pile burning in Colorado's Front Range has negative impacts that may be of interest to land managers. This study observed 2 year old fire scars for two years post-restoration treatment and in this instance the addition of native seed appears to best initiate vegetation growth in fire scars indicating that a lack of plant propagules is the main limiting factor. Continuing to monitor these scars may help inform management decisions in the long-term.

5. MANAGEMENT IMPLICATIONS

Seeding fire scars had the most significant positive impact on vegetation recovery during this study. Though I noticed significantly altered soil physical and chemical effects, many surface manipulations were either unable to mitigate the impacts or did little to promote revegetation. However, if sensitive ecosystems are present, woodchip mulch added to scars may reduce the likelihood of excess nitrogen leaching into waterways. The results of this study indicate that seeding fire scars may be the best method for increasing vegetation cover in the short-term while the addition of woodchips may alter nitrogen availability. Early observations indicate that the fire scars in this study are recovering, with or without surface manipulations; however, due to the short duration of this study (2 years) further research may be required. Longer-term monitoring may better clarify if and why scars remain visible on the landscape for many years in some instances and recover more quickly in others.

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7. APPENDICES

Appendix 1. Effect of slash pile burning on percent vegetation cover within conifer forests of the Front Range of Colorado, USA. Vegetation cover data was collected by position approximately 3 years post-burn from untreated fire scars (August 2010). Mean values (± 1 standard error) shown by position. Position effects were determined on untransformed data using the Cochran-Mantel-Haenszel statistic. Different letters indicate significant differences between positions at p=0.05 using Tukey's posthoc test on untransformed data. Species that could not be identified were analyzed in the total vegetation analysis but were removed during analysis of functional groups, accounting for any discrepancy between functional group totals and vegetation totals.

	Position					
	Center		Edge		Reference	
Total Bareground	**69.60 (5.04)**	***a***	**33.86 (5.75)**	***b***	**5.37 (2.73)**	***c***
Total Litter	**18.22 (3.42)**	***b***	**44.39 (5.93)**	***a***	**62.06 (6.18)**	***a***
Total Vegetation Cover	**12.18 (5.08)**	***b***	**21.76 (5.40)**	***ab***	**32.57 (6.13)**	***a***
Annual and biennial forb						
Chenopodium fremontii	1.21 (1.12)		2.19 (2.19)		0.00 (0.00)	
Chenopodium leptophyllum	0.88 (0.62)		0.44 (0.44)		0.00 (0.00)	
Cirsium vulgare	*0.00 (0.00)*		*3.15 (3.04)*		*0.00 (0.00)*	
Conyza canadensis	0.00 (0.00)		1.54 (1.54)		0.00 (0.00)	
Collomia grandiflora	0.00 (0.00)		0.00 (0.00)		0.00 (0.00)	
Galium aparine	0.00 (0.00)		0.00 (0.00)		0.00 (0.00)	
Gayophytum diffusum	1.10 (1.10)		0.00 (0.00)		0.00 (0.00)	
Gentianella amarella	0.00 (0.00)		0.00 (0.00)		0.00 (0.00)	
Lactuca serriola	0.00 (0.00)		0.00 (0.00)		0.00 (0.00)	
Sisymbrium altissimum	0.00 (0.00)		0.00 (0.00)		0.00 (0.00)	
Verbascum thapsus	*0.00 (0.00)*		*0.00 (0.00)*		*0.00 (0.00)*	
Total	**3.18 (1.87)**	***a***	**7.32 (3.83)**	***a***	**0.00 (0.00)**	***a***

	Position		
	Center	Edge	Reference
Perennial forb			
Achillea millefolium	0.34 (0.34)	0.22 (0.22)	0.77 (0.56)
Allium cernuum	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
Aliciella pinnatifida	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
Antennaria anaphaloides	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
Antennaria parvifolia	0.00 (0.00)	0.11 (0.11)	0.11 (0.11)
Androsace septentrionalis	0.00 (0.00)	0.21 (0.21)	0.00 (0.00)
Apocynum androsaemifolium	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
Artemisia campestris	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
Arnica cordifolia	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
Arenaria fendleri	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
Artemisia frigida	2.08 (1.97)	0.00 (0.00)	0.00 (0.00)
Arabis glabra	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
Arabis hirsuta	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
Artemisia ludoviciana	0.00 (0.00)	0.77 (0.77)	0.33 (0.24)
Arnica mollis	0.00 (0.00)	0.21 (0.21)	0.00 (0.00)
Astragalus laxmannii	0.00 (0.00)	0.00 (0.00)	1.75 (1.64)
Bahia dissecta	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
Campanula rotundifolia	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
Cerastium arvense	*0.00 (0.00)*	*0.00 (0.00)*	*0.00 (0.00)*
Centaurea diffusa	*0.00 (0.00)*	*0.00 (0.00)*	*0.00 (0.00)*
Chamerion angustifolium	0.22 (0.22)	0.33 (0.33)	0.00 (0.00)
Cirsium arvense	*0.00 (0.00)*	*0.00 (0.00)*	*0.33 (0.33)*
Epilobium ciliatum	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
Erysimum capitatum	0.00 (0.00)	0.00 (0.00)	0.11 (0.11)

	Position		
	Center	Edge	Reference
Erigeron compositus	0.00 (0.00)	0.00 (0.00)	0.11 (0.11)
Erigeron peregrinus	0.00 (0.00)	0.00 (0.00)	0.33 (0.33)
Eriogonum umbellatum	0.00 (0.00)	0.00 (0.00)	0.11 (0.11)
Frasera speciosa	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
Fragaria virginiana	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
Gaillardia aristata	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
Geranium caespitosum	0.00 (0.00)	0.00 (0.00)	0.55 (0.39)
Grindelia squarrosa	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
Harbouria trachypleura	0.00 (0.00)	0.00 (0.00)	0.22 (0.22)
Heuchera parvifolia	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
Heterotheca villosa	0.33 (0.33)	0.75 (0.75)	0.22 (0.15)
Lupinus argenteus	0.00 (0.00)	0.35 (0.35)	0.44 (0.44)
Mertensia lanceolata	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
Packera fendleri	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
Penstemon secundiflorus	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
Penstemon virens	0.00 (0.00)	0.00 (0.00)	0.55 (0.31)
Phacelia heterophylla	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
Phacelia sericea	0.00 (0.00)	1.97 (1.97)	2.19 (2.19)
Physaria vitulifera	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
Potentilla fissa	0.00 (0.00)	0.00 (0.00)	0.22 (0.15)
Potentilla hippiana	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
Pseudocymopterus montanus	0.00 (0.00)	0.75 (0.75)	0.00 (0.00)
Pulsatilla patens	0.00 (0.00)	0.00 (0.00)	0.33 (0.24)
Scutellaria brittonii	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
Senecio eremophilus	0.00 (0.00)	0.00 (0.00)	0.11 (0.11)
Sedum lanceolatum	0.00 (0.00)	0.00 (0.00)	0.11 (0.11)

	Position					
	Center		Edge		Reference	
Solidago nana	0.00 (0.00)		0.00 (0.00)		0.00 (0.00)	
Solidago simplex	0.11 (0.11)		0.00 (0.00)		0.33 (0.24)	
Symphyotrichum porteri	0.00 (0.00)		0.00 (0.00)		0.00 (0.00)	
Thermopsis divaricarpa	0.00 (0.00)		0.66 (0.45)		1.32 (0.92)	
Total	**3.08 (1.97)**	***a***	**6.34 (2.31)**	***a***	**10.53 (2.73)**	***a***
Annual grass						
Bromus arvensis	0.00 (0.00)		0.21 (0.21)		0.00 (0.00)	
Bromus tectorum	*2.41 (2.41)*		*0.54 (0.54)*		*0.00 (0.00)*	
Total	**2.41 (2.41)**	***a***	**0.75 (0.75)**	***a***	**0.00 (0.00)**	***a***
Perennial grass						
Agrostis scabra	1.64 (1.26)		1.97 (1.86)		0.66 (0.48)	
Bouteloua gracilis	0.00 (0.00)		0.00 (0.00)		0.00 (0.00)	
Bromus inermis	0.00 (0.00)		0.00 (0.00)		0.00 (0.00)	
Bromus porteri	0.00 (0.00)		0.00 (0.00)		0.00 (0.00)	
Calamagrostis purpurascens	0.00 (0.00)		1.21 (1.21)		0.00 (0.00)	
Carex rossii	1.86 (1.28)		3.07 (2.28)		4.17 (1.80)	
Danthonia spicata	0.00 (0.00)		0.00 (0.00)		1.32 (1.32)	
Elymus elymoides	0.00 (0.00)		0.00 (0.00)		0.00 (0.00)	
Elymus lanceolatus	0.00 (0.00)		0.00 (0.00)		0.00 (0.00)	
Elymus trachycaulus	0.00 (0.00)		0.00 (0.00)		0.00 (0.00)	
Festuca arizonica	0.00 (0.00)		0.00 (0.00)		0.00 (0.00)	
Hesperostipa comata	0.00 (0.00)		0.00 (0.00)		0.00 (0.00)	
Koeleria macrantha	0.00 (0.00)		0.00 (0.00)		0.00 (0.00)	
Leucopoa kingii	0.00 (0.00)		0.00 (0.00)		0.11 (0.11)	

	Position		
	Center	Edge	Reference
Muhlenbergia montana	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
Pascopyrum smithii	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
Poa compressa	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
Poa fendleriana	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
Poa pratensis	0.00 (0.00)	0.00 (0.00)	0.11 (0.11)
Total	**3.51 (1.70)** ***a***	**6.25 (4.20)** ***a***	**6.36 (2.74)** ***a***
Shrub			
Arctostaphylos uva-ursi	0.00 (0.00)	0.00 (0.00)	6.69 (2.90)
Juniperus communis	0.00 (0.00)	0.00 (0.00)	7.46 (5.02)
Mahonia repens	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
Purshia tridentata	0.00 (0.00)	0.00 (0.00)	0.88 (0.88)
Ribes cereum	0.00 (0.00)	0.33 (0.33)	0.00 (0.00)
Rosa woodsii	0.00 (0.00)	0.33 (0.33)	0.00 (0.00)
Rubus idaeus	0.00 (0.00)	0.44 (0.34)	0.00 (0.00)
Total	**0.00 (0.00)** ***a***	**1.10 (0.54)** ***b***	**15.02 (5.55)** ***b***
Tree			
Juniperus scopulorum	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
Pinus contorta	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
Pinus ponderosa	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
Populus tremuloides	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
Pseudotsuga menziesii	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
Total	**0.00 (0.00)** ***a***	**0.00 (0.00)** ***a***	**0.00 (0.00)** ***a***

Appendix 1 con't.

	Position effect	
ANOVA results	*Statistic*	*Probability*
Total Bareground	29.51	**<0.001**
Total litter	20.67	**<0.001**
Annual and biennial forb	5.38	0.068
Annual grass	2.00	0.368
Perennial forb	7.50	**0.024**
Perennial grass	2.67	0.264
Shrub	9.17	**0.010**
Tree	0.00	0.273
Total vegetation	3.70	0.035