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Recovery of small pile burn scars in conifer forests of the Colorado Front Range

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ABSTRACT

The ecological consequences of slash pile burning are a concern for land managers charged with maintaining forest soil productivity and native plant diversity. Fuel reduction and forest health management projects have created nearly 150,000 slash piles scheduled for burning on US Forest Service land in northern Colorado. The vast majority of these are small piles (<5 m diameter). Similar to larger piles, we found that burning small piles had significant immediate effects on soil nutrients and physical and chemical properties and native plant cover. To evaluate the need to rehabilitate small piles and compare the effectiveness of treatment options, we examined soil and plant responses to treatments designed to alter soil nutrients, moisture and temperature and to increase seed availability. We compared four surface treatments (soil scarification, woodchip mulch, tree branch mulch, untreated scars), with and without addition of a native seed mixture. Natural recovery and treatment effects were examined for 2.5 years after pile burning at 19 conifer forest sites along the Colorado Front Range. Woodchip mulch had dramatic effects on soil moisture, temperature, decomposition and inorganic soil N compared to the other treatments, untreated scars or unburned areas; woodchip mulch also suppressed plant establishment. Seeding increased total native species richness as expected, but had marginal effects on forb cover and no effect on graminoid cover. Soil N availability and plant cover did not differ from unburned areas in the absence of surface or seeding treatments within two years of pile burning. Neither reduced seed availability nor altered soil properties following burning hindered revegetation of these small burn scars by native herbaceous plants. Our findings indicate that rehabilitation may not be required for small burn pile scars except in sensitive areas, such as those with water quality and invasive plant concerns.

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1. Introduction

Slash burning has long been used to reduce wildfire risk and surface fuel loads after harvesting and fuel reduction treatments in western North American forests (Isaac and Hopkins, 1937; McCulloch, 1944). Accumulating and burning logging slash and non-merchantable woody material in piles has effects on vegetation and soils that are typically more severe than those of either wildfire or broadcast burning (Ahlgren and Ahlgren, 1960; DeBano et al., 1998; Wan et al., 2001; Certini, 2005). Extreme temperatures that penetrate soil beneath burning slash piles can destroy seed reserves and plant tissues and alter physical, chemical and biological soil properties (Busse et al., 2010). The immediate effects of pile burning on soil microbes, acidity, organic matter and plant nutrients (Tarrant, 1956; Covington et al., 1991; Wan et al., 2001) and longer-term effects relating to loss of aggregate structure, decreased water infiltration, and mineralogical and color changes (Dyrness and Youngberg, 1957; Debano and Rice, 1973; Ulery et al., 1993; Busse et al., 2010; Rhoades and Fornwalt, 2015) have been documented for more than a half century. More recently, elevated nutrients, altered water relations and exposed soil surfaces of pile burn scars have been shown to favor non-native plant establishment (Haskins and Gehring, 2004; Korb et al., 2004; Creech et al., 2012) and threaten surface water quality (Johnson et al., 2011). Though its effects are well-characterized, few studies have examined the need to actively rehabilitate burn scars to facilitate community and ecosystem recovery.

Organic mulches and other amendments and treatments are commonly used to try to rehabilitate soils, speed native plant recovery and limit weedy plant establishment after pile burning. Such treatments have been shown to ameliorate seedbed temperature and soil moisture extremes, restore soil nutrients and the microbial processes that regulate them, and replace lost seed reserves (Korb et al., 2004; Fornwalt and Rhoades, 2011; Creech

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et al., 2012). Native understory plant cover was increased within burn scars in Arizona ponderosa pine forests and that of non-native and ruderal species was reduced by addition of topsoil containing mycorrhizal spores (Korb et al., 2004). Woodchip mulch has been shown to reduce the elevated levels of inorganic soil N that follow pile burning (Fornwalt and Rhoades, 2011) and may also increase soil moisture and dampen soil temperature fluctuations (Rhoades et al., 2012). Scarification to disrupt sealed surface soils and hydrophobic layers has potential to enhance water infiltration and revegetation of areas affected by burning (Robichaud et al., 2000; Fornwalt and Rhoades, 2011). The previous studies document that seeding combined with surface amendments increased plant establishment more than surface or seeding treatments alone (Korb et al., 2004; Fornwalt and Rhoades, 2011). However, burn scar rehabilitation may not be economically feasible or ecologically necessary in all conditions; the need for rehabilitation and appropriate treatments are likely to vary with pile size and management objectives.

Fuel reduction and forest health management activities on US Forest Service land in northern Colorado alone have created >140,000 piles scheduled for burning (USFS, 2010) and thousands of additional piles have been created on county, state and National Park Service lands. Most of these were small hand-built or machine-built piles (<5 m diameter) that can cover considerable portions (>15%) of treatment areas (Busse et al., 2013). Federal regulations (National Forest Management Act of 1976; US P.L. 94-588) stipulate that management activities must not permanently degrade the productive capacity of soils and Best Management Practices (US Forest Service, 2006) prescribe active rehabilitation where soil damage is severe or exceeds 15% of a treated area (US Forest Service, 2006). However, despite their high numbers and common occurrence along roads and stream corridors, small burn scars have not typically been rehabilitated.

Simple, low-cost treatments aimed at rehabilitating exposed, fire-altered soils and establishing native plants may be relevant to fuels and forest management efforts in conifer forests of northern Colorado and throughout western North America. Managers confronted with a surplus of small, slash piles must consider whether to actively rehabilitate burn scars or allow natural processes to restore them. To inform this decision, we first characterized the consequences of burning small slash piles and then compared soil and plant responses to surface rehabilitation and seeding treatments. We measured soil temperature and moisture, inorganic soil nitrogen, microbially-mediated decomposition and plant cover and species diversity to assess if the treatments were effective at ameliorating soil and seedbed conditions. This work will help determine if rehabilitation is worthwhile to facilitate recovery of small burn scars within 3 years of pile burning.

2. Methods

2.1. Study sites and rehabilitation treatments

The study was established at twenty hazardous fuel treatment project sites distributed along a 90 km latitudinal band of the northern Front Range, west of Boulder and Fort Collins, Colorado, USA (39°56′N to 40°45′N). The sites, which were located on US Forest Service (Arapaho-Roosevelt National Forest) and Boulder County Open Space land, ranged in elevation from 2214 to 2772 m (see on-line map). Ponderosa pine (*Pinus ponderosa*) and Douglas-fir (*Pseudotsuga menziesii*) are dominant overstory species at lower elevations (2200–2600 m) and lodgepole pine (*Pinus contorta*) is dominant at higher elevations (above 2700 m). Annual precipitation averages 440 and 385 mm for climate stations located near the southern and northern extent of the study area (WRCC, 2013). January minimum temperatures average −9.2 °C and −11.2 °C and July maximum temperatures average 26.3 °C and 24.6 °C within the study area. The northern Front Range is underlain by crystalline, granitic and metamorphic bedrock that weathers into coarse-textured soils. In general, soils at the study sites are classified as loamy skeletal Eutrocryepts, Dystrocryepts and Haplustalfs (NRCS, 2013a).

Slash piles at the study sites were created from canopy and ladder fuels harvested in 2006 and 2007. The resulting biomass was hand-piled and burned during winter 2008/2009 at all sites. The twenty study locations represented the range of forest, soil and site topography typical of Front Range conifer forests. Within a given site, we selected ten burn scars that had similar size, shape, surrounding vegetation and burn severity (estimated from consumption of woody fuel) during summer 2009. Burn scars spanned 2.1–5.4 m in diameter (3.5 m mean).

Surface (untreated control, hand scarification, branch mulch, and woodchip mulch) and seeding treatments (with and without the addition of native plant seeds) were randomly assigned in a factorial experimental design in summer 2009, with each treatment combination replicated once per site (Fig. S1). 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. Woodchips were created on-site and applied in a ~10 cm mulch layer; chip pieces were relatively uniform (~2–10 cm long by 1–2 cm thick). The mulch application depth was based on previous research in Front Range conifer forests that showed more consistent reductions in soil N availability under thicker mulch (15 vs 7.5 cm) (Rhoades et al., 2012). Tree branches from forest thinning operations were placed on the fire scars to create approximately 50% shade on the branch mulch treatment based on hand-held light meter measurements. Seeded piles received a mixture of 32 species native to conifer forests of Colorado's northern Front Range (Table S2). Plants included 20 species of annual, biennial, or perennial forbs, 10 perennial grass species and 2 perennial shrub species. Seeds were hand-collected from local populations or purchased from regional suppliers. All hand-collected seed was tested for purity and germination at the Colorado State University Seed Laboratory. The mixture was hand-broadcast at a rate of 2700 pure live seeds m^{-2} with forbs added at approximately 3 times the rate of grasses. A garden rake was used to roughen a 1 cm seedbed prior to seeding. Burn scars were seeded after scarification but prior to mulching. Soil was tamped with a McLeod to improve seed to soil contact after seeding.

2.2. Soil and plant sampling and analysis

We examined the initial effects of pile burning on soils in 2010 (1.5 years after burning) and on plants in 2010 and 2011 (1.5 and 2.5 years after burning) at two untreated scars per site. The 2010 sampling was conducted at twenty fuel reduction project sites; a fall 2010 wildfire eliminated one site from subsequent sampling. To gauge burn effects we sampled the interior of each burn scar, a 0.5 m band inside the scar perimeter, and the unburned area adjacent to each scar, 2 m beyond the scar perimeter. It was not possible to differentiate the edge zone once surface treatments were established (2009), so treatment comparisons were made for the interior zone only (2010 and 2011).

We compared soil physical and chemical properties by scar zone for untreated pile burn scars. Soil hydraulic conductivity was determined using a field infiltrometer designed to assess wildfire effects (Decagon Devices, Pullman, WA). We recorded the volume of water infiltrating during 60 s periods (2 subsamples per scar zone). We assessed soil aggregate stability using a qualitative slaking assay on 1–2 cm diameter aggregates (Herrick et al., 2001) collected from the upper 5 cm of mineral soil (6 subsamples per