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Pile burning creates a fifty-year legacy of openings in regenerating lodgepole pine forests in Colorado

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ABSTRACT

Pile burning is a common means of disposing the woody residues of logging and for post-harvest site preparation operations, in spite of the practice's potential negative effects. To examine the long-term implications of this practice we established a 50-year sequence of pile burns within recovering clear cuts in lodgepole pine forests. We compared tree, shrub and herbaceous plant abundance and documented indicators of soil degradation in openings where logging residue was piled and burned as part of post-harvest site preparation and the adjacent forests regenerating after clear cutting. We found that pile burning creates persistent 10–15 m diameter openings with lower tree densities (<500 trees ha^{-1}; stems >2.54 cm diameter at 1.4 m height) compared to surrounding regenerating pine stands (2000–5000 trees ha^{-1}). Low tree seedling and sapling densities (stems <2.54 cm diameter at 1.4 m height) in the openings (10–20% of regenerating forest), suggest they will remain poorly-stocked into the future. We observed evidence of high severity burning, including layers of soil charcoal and hardened red soil across the time series, but no sign that water infiltration, compaction or other indicators of soil degradation were consistent barriers to plant recolonization. Forb and graminoid cover, for example, was higher in the burn scar openings compared to regenerating forests. Pile burn openings are formed by the loss of pine seed during burning and short-term soil changes, but it is uncertain what factors maintain the openings during subsequent decades. As conducted for site preparation, the herbaceous plant-dominated openings are not extensive (<5% cover within clear cut units), and we found few invasive, non-native plants and no indication that soil conditions were sufficiently altered to explain 50 years of poor tree regeneration. Nevertheless, persistence of the openings and recent increases in the number and size of piles from fuels and bark beetle salvage treatments has prompted resource managers to consider options for utilization and on-site retention of harvest residue.

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1. Introduction

Slash burning has long been used to reduce wildfire risk and to promote tree regeneration after harvesting in western North American forests (Isaac and Hopkins, 1937; McCulloch, 1944; Boe, 1956). Historic wildfires in the Pacific Northwest (Wells, 2004), Northern Rockies (Lyman, 1947), and elsewhere, that ignited in cutover forests with heavy slash accumulations resulted in a general policy of piling and burning slash to dispose of woody residue to reduce fuel loads. Recent growth of biomass energy markets that utilize small-diameter material (Fahey et al., 2010; Klockow et al., 2013) and development of equipment for conducting on-site fuel reduction treatments (Rummer et al., 2003; Hartsough et al., 2008) broaden options for disposing woody residue, yet pile burning remains a common slash disposal method. For example, in northern Colorado where bark beetle outbreaks in lodgepole pine forests have resulted in a rapid increase in treatments to reduce woody fuels and tree fall hazards, salvage dead timber, and regenerate new forests (Collins et al., 2010), the inventory of piles that await burning exceeds 140,000 (US Forest Service, 2012, R2, unpublished records).

The influence of slash pile burning on soil temperature (Roberts, 1965) and soil chemical and physical properties (Tarrant, 1956a; Dyrness and Youngberg, 1957) have been researched for more than 50 years. The quantity, arrangement and moisture content of fuels within burn piles are intended to promote complete combustion and as a result, the short-term effects of pile burning are more severe in concentrated areas than those of either wildfire or broadcast burning (Ahlgren and Ahlgren, 1960; Wells et al., 1979; DeBano et al., 1998; Wan et al., 2001). The temperatures that

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penetrate the soil beneath burning slash piles (Massman et al., 2008; Busse et al., 2010) can destroy seed reserves and plant tissues (Keeley and Fotheringham, 2000) and change physical, chemical and biological soil properties (Certini, 2005). The extreme heating often has immediate effects on soil microbes, acidity, organic matter and plant nutrients (Fowells and Stephenson, 1934; Tarrant, 1954 and Tarrant, 1956a; Covington et al., 1991; Wan et al., 2001). Elevated levels of plant-available soil nutrients and exposed mineral soil in pile burn openings can improve plant seeding growth (York et al., 2009) favor establishment of weedy, non-native species (Haskins and Gehring, 2004; Korb et al., 2004; Creech et al., 2012) and threaten water quality through nutrient leaching and surface runoff (Johnson et al., 2011) for months to years following combustion. Loss of aggregate structure, decreased water infiltration and formation of hardened, red soils are common in the surface soils of pile burn scars and may last for multiple years after burning (Isaac and Hopkins, 1937; Tarrant, 1956b; Dyrness and Youngberg, 1957; Ulery and Graham, 1993; Ketterings et al., 2000).

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. Where severe soil damage (defined by severe burning, compaction, erosion, or displacement) occurs or its spatial extent exceeds 15% of a treatment unit, rehabilitation may be warranted (US Forest Service, 2006). The negative consequences of pile burning are most apparent for large piles constructed at log landings and timber processing areas often along permanent roads, where soils are influenced by a combination of topsoil displacement, compaction and fire effects. These areas are high priority for rehabilitation, typically involving mechanical decompaction and seeding of herbaceous plants (US Forest Service, 2012). In contrast, burn scars created on federal land during site preparation and scars from smaller, mechanical- and hand-built pile burns are rarely considered priorities for rehabilitation.

Land managers require information about the long-term consequences of pile burning to evaluate rehabilitation needs or justify alternatives to pile burning. To address this knowledge gap, we used US Forest Service (USFS) stand activity records, aerial photographs and local knowledge to develop a 50-year record of site preparation pile burning after clear cutting (Fig. 1), and then we quantified tree regeneration, understory plant cover and indicators of soil degradation in pile burn openings and adjacent forests. This project did not attempt to disentangle the ecological processes responsible for maintaining the forest openings; such work is the aim of on-going experimental studies and pile burn rehabilitation research (Fornwalt and Rhoades, 2011; Rhoades et al., unpublished data).

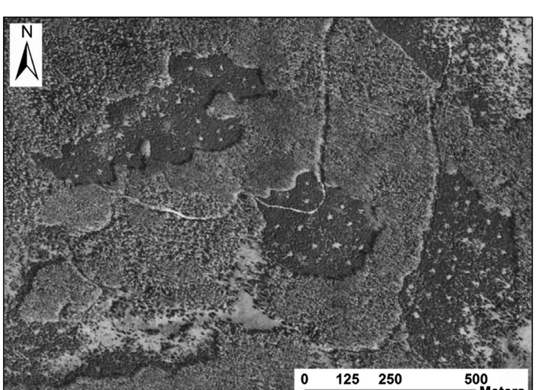

Fig. 1. Pile burn scars created during post-harvest site preparation in lodgepole pine clear cuts conducted during 1986 on the Parks Ranger District, Medicine Bow–Routt National Forests. The 2011 photograph is centered near 40°26′39″N; 106°4′10″W at 2815 m elevation. The US Department of Agriculture image may be accessed at: www.googleearth.com.

2. Methods

The study was conducted in northern Colorado on USFS land administered by the Medicine Bow–Routt National Forests. Study sites span a 500 km^2 portion of the Parks Ranger District at a mean elevation of 2900 m. Total annual precipitation averages 660 mm (Willow Creek Pass, SNOTEL Site, Natural Resources Conservation Service, 2012; National Climate Data Center, 2012). Mean annual temperature is 3 °C with average January minima and July maxima of −9 and 15 °C, respectively. Soils are formed in sandstone, siltstone and conglomerate residuum and colluvium and are moderately deep and well-drained to excessively well-drained. The most abundant soil types are loamy-skeletal, Typic Cryoboralfs and sandy-skeletal, Typic Cryochrepts. The area is part of the Southern Rocky Mountain Steppe Ecoregion (Bailey, 1998). Lodgepole pine (*Pinus contorta* var. *latifolia*) is the dominant tree species in the area, growing in relatively pure, even-aged stands on southerly aspects, lower elevation and flatter landscape locations. Lodgepole grows in association with subalpine fir (*Abies lasiocarpa*), Engelmann spruce (*Picea engelmannii*) and quaking aspen (*Populus tremuloides*) on mesic north-facing slopes and higher elevations (Collins et al., 2011).

Lodgepole pine forests in this region are typically regenerated with clear cut harvests (Lotan and Critchfield, 1990; USFS, 1998). Post-harvest site preparation activities, consisting of piling and burning logging debris, aim to reduce surface fuel loads and create a seedbed to stimulate tree recruitment and ensure adequate stocking in regenerating forests (Lotan and Perry, 1983). Site preparation slash piling is conducted with a tractor-mounted brush rake, blade or grapple hook. Pile burning typically occurs within a few years of harvesting and during winter months when there is adequate snow cover to reduce the risk of unintended ignition. Post-burn, rehabilitation is limited to large piles located on log landing sites along haul roads where high severity burning and soil compaction are evident (USFS, 2006 and 2012); piles created by site preparation are distributed more evenly within clear cut harvest units and are not usually rehabilitated.

We used USFS stand activity records to locate harvest units where pile burn operations had been conducted; such records extend from the present to the 1960s for the Medicine Bow–Routt National Forests. Within historic harvest areas pile burn openings were identified on true-color aerial photographs and individual pile locations were transferred to digital media using GIS software (ArcGIS V. 10, ESRI, Redlands, CA). Photographs taken at multiple times after harvesting helped confirm pile scar locations within regenerating forests. We limited sampling to clear cut, lodgepole pine stands and piles created during post-harvest site preparation that were subsequently burned but not rehabilitated. To facilitate comparisons, we avoided burn scars created on logging decks where the large pile size, proportion of large wood and degree of soil compaction differ from piles made within harvest units.

Stand treatment records for the Medicine Bow–Routt National Forests include 1761 treatments units where pile burning was conducted from the 1960s through the 2000s (Fig. 2a). Over that period, treatments were conducted on 180 km^2 of forest land, primarily as clear cut harvests (∼70%). Treatment activity peaked during the 1980s and 1990s when harvesting and pile burning were conducted on 5000 and 10,000 ha, respectively. Our aerial photography survey identified 7500 site preparation scars, averaging from 500 to 5000 per decade over the past 50 years (Figs. 1 and 2b).

We randomly selected 10 harvest units per decade from the 1960s through the 2000s. In each of 50 harvest units we randomly selected five individual pile burn openings. The 50 clear cut units