Forest Ecology and Management 360 (2016) 40–51

Contents lists available at ScienceDirect

Forest Ecology and Management

journal homepage: www.elsevier.com/locate/foreco

Finding balance between fire hazard reduction and erosion control in the Lake Tahoe Basin, California–Nevada

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ARTICLE INFO

Article history:
Received 14 July 2015
Received in revised form 16 October 2015
Accepted 16 October 2015

Keywords:
Fuels management
Mastication
Prescribed fire
Runoff simulation
Snowmelt

ABSTRACT

The 2007 Angora Fire served as a stark reminder of the need for fuel reduction treatments in the Lake Tahoe Basin, California–Nevada, USA. Concerns exist, however, that the corresponding removal of forest floor fuels could increase erosion rates, negatively affecting the clarity of Lake Tahoe. To quantify trade-offs between fuel reduction and erosion, we conducted field-based snowmelt runoff simulation experiments at 16 sites within the Lake Tahoe Basin that had received mechanical mastication or prescribed fire treatments. Erodibility was measured to determine if thresholds of litter, duff, and woody fuel cover could be established that are sufficient for trapping sediment and increasing infiltration, without contributing to fire hazard. Field snow-melt simulations revealed that as little as 25% of the ground surface covered with masticated fuels over duff was sufficient to mitigate erosion. The post-prescribed fire environment characterized by heterogeneous patches of exposed bare mineral soil interspersed with unburned patches mitigated erosion by increasing infiltration. Considerable increases in sediment yield were observed in plots with >35% of ground area burned; the highest total sediment yields (values) occurred in plots where between 66% and 100% of the soil surface burned. Our field results suggest that erosion and wildfire severity can be simultaneously mitigated through the use of masticated fuel reduction treatments or prescribed fire treatments that leave sufficient organic matter to trap sediment but have sufficiently low fuel loading and/or enough fuel discontinuity or patchiness to limit fire spread.

1. Introduction

Restoring ecosystem structure, composition, and function while reducing fire hazard are primary goals of land management in many fire-prone landscapes worldwide (Allen et al., 2002; Stephens et al., 2012; Ryan et al., 2013). In dry western North American forests and woodlands, these treatments often focus on modifying overstory structure and surface woody fuel to diminish fireline intensity, crown ignition, and canopy fire spread (Agee and Skinner, 2005). The unintended consequences of fuels treatments for wildlife habitat, plant community composition, non-native species spread, and erosion are often overlooked (Hunter et al., 2006). Hillslope runoff from disturbed soils in burned landscapes is a major concern for land managers because fine suspended particles transport nutrients that contribute to eutrophication and losses in clarity of receiving water bodies (Goldman et al., 1989).

Efforts to minimize wildfire hazard can oftentimes conflict with those meant to reduce the potential for erosion (Shakesby et al., 1993). Woody fuels and litter limit erosion by protecting the soil from rainsplash, reducing the occurrence of overland flow processes, trapping sediment passing over the soil surface, impeding the formation of rills, and increasing infiltration rates (Robichaud, 2000). Litter, duff, and down woody materials can reduce turbidity, erosion rates, and sediment yields (MacDonald and Stednick, 2003; Robichaud et al., 2010). A continuous cover of surface fuels provides the greatest opportunity to minimize the potential for erosion. However, distributing surface fuel cover evenly over the landscape leads to fuel continuity which also increases the potential fire hazard. Ironically, failing to reduce fire hazard can result in severe erosion when wildfire ultimately occurs (Silins et al., 2009).

We hypothesize that the solution to this apparent paradox can be found through mimicking the patchy burn mosaic of historic fire

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http://dx.doi.org/10.1016/j.foreco.2015.10.030
0378-1127/

regimes in any fuel reduction treatment, including prescribed burning or mastication (Fig. 1). There is evidence that historical Sierra Nevadan mixed-conifer forests reflected this desirable spatial heterogeneity and forest floor fuel discontinuity (Taylor, 2004; Knapp and Keeley, 2006; Rocca, 2009). Fires occurred frequently in the Sierras, resulting in relatively low fuel loads and discontinuous fuels, (Show and Kotok, 1924) producing patchy burns and reinforcing heterogeneity in fire severity. A century of fire exclusion has resulted in fuel continuity and forest types prone to severe wildfire that are uniformly intense over large spatial scales (Miller and Urban, 2000; Allen et al., 2002; Schoennagel et al., 2004; Hessburg et al., 2005; Knapp et al., 2005; Donovan and Brown, 2007). The absence of conditions conducive to burn patchiness in contemporary forests limits the formation of unburned islands of groundcover that serve to slow erosion and increase infiltration of runoff (Martin and Sapsis, 1992). Rainfall simulation experiments conducted by Johansen et al. (2001) indicated that post-fire sediment yields increased dramatically when percent bare soil exceeded a threshold of 70%.

We designed an experiment to test this "patchy burn" hypothesis, with fuel reduction treatments spanning a range of bare soil and groundcover to better understand thresholds for optimizing both erosion control and reduction of fire hazard. Field-based simulation of rill erosion resulting from snowmelt runoff was conducted within forested areas of the Lake Tahoe Basin treated with mechanical mastication and prescribed fire. Observed erosion characteristics (sediment yields, particle diameters, and infiltration percentages) were correlated with detailed site depictions (fuel bed characteristics, soil properties, and slope steepness), to determine optimal levels of surface fuel retention for mechanical mastication and prescribed fire treatments.

Fig. 1. Above: Mastication treatments in the Lake Tahoe Basin reduce stand density and produce a compact but continuous fuelbed (Photo: J. Kane). Below: Forest floor after an early-season prescribed burn in mixed conifer forest fuels similar to those found in the Lake Tahoe Basin.

2. Materials and methods

2.1. Study site

The study was performed at Lake Tahoe, California–Nevada, USA, where these erosion and fire management issues have great relevance. Over the past 25 years, slowing or reversing the loss of clarity of the lake (−30% over three decades) has become an issue of primary importance (Jassby et al., 1994; Swift et al., 2005; Grismer and Ellis, 2006). The social and economic priority of these efforts is rivaled only by the necessity to mitigate effects of wildland fire. The 2007 Angora Fire in South Lake Tahoe, CA burned 1254 ha of mixed-conifer forest, destroyed 254 residential and 75 commercial structures, and led to firefighting costs that exceeded US $11 million (Safford et al., 2009; California Department of Forestry and Fire Protection, 2011). The rapid spread of this wildfire was due in part to fuels that had accumulated in the absence of periodic fire (Safford et al., 2009).

The Lake Tahoe Basin is situated near the crest of the Sierra Nevada at an elevation of 1900 m above sea level at the lake and 2700 m at the crest (Coats et al., 1976). The majority of annual precipitation (average = 800 mm) falls as snow between November and April (Western Regional Climate Center, 2010). Annual snowmelt primarily occurs in the late spring to early summer. Dramatic flood events occasionally occur when warm rains fall on the accumulated snow. Of the 1363 km^2 Basin, 800 km^2 is a forested watershed drained by 63 small streams, with the remainder lake surface (Fig. 2, Goldman, 1988). Lake Tahoe is a large, deep, oligotrophic, sub-alpine lake with a mean depth of 333 m (Gardner et al., 2000). The combination of great depth, small ratio of watershed to lake area, and granitic basin geology has produced a lake of extremely low fertility and high transparency (Jassby et al., 1994; Swift et al., 2005).

This study focused on two fuels management approaches (prescribed fire and mechanical mastication) widely employed within the Lake Tahoe Basin and many other fire-prone western USA forests. Mastication is the process of mechanically converting live or dead standing biomass into surface fuel by chipping or breaking up larger pieces into smaller portions resulting in dense woody fuelbeds (Kane et al., 2009) (Fig. 1). Prescribed fire is the deliberate application of fire to forest fuels to meet a wide spectrum of management goals including reducing the intensity of subsequent wildfire (Wade and Lunsford, 1989; Ryan et al., 2013). These treatments are both effective at reducing fire hazard, but mastication results in a compact, relatively uniform layer of woody fuels while prescribed fire partially or fully consumes surface forest floor and woody fuels.

Research was conducted in 16 forested sites throughout the Basin, eight of which were positioned in areas where recent mastication treatments occurred (within the same season) and eight where prescribed fires occurred (Fig. 2 and Table 1). Sites were selected with moderate to steep slopes (15–48%) typical for the Basin and steep enough for runoff to be potentially generated within plots. Research sites were all on common soil types within the Basin, broadly characterized as granitic, volcanic or a mixture of the two, with surface soil textures of cobbly or stony sandy loams and parent materials that included granite, granodiorite, metamorphics, and extrusive lavas (Naslas et al., 1994). All sites were dominated by a Sierran mixed-conifer forest consisting of Jeffrey pine (*Pinus jeffreyi*), ponderosa pine (*P. ponderosa*), sugar pine (*P. lambertiana*), white fir (*Abies concolor*), red fir (*A. magnifica*), and incense-cedar (*Calocedrus decurrens*). Common shrub associates included huckleberry oak (*Quercus vacciniifolia*), greenleaf manzanita (*Arctostaphylos patula*), mountain whitethorn (*Ceanothus cordulatus*), and mountain sagebrush (*Artemisia tridentata*).