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Effectiveness of fuel treatments for mitigating wildfire risk and sequestering forest carbon: A case study in the Lake Tahoe Basin

E. Louise Loudermilk[a,*], Alison Stanton[b,1], Robert M. Scheller[a,2], Thomas E. Dilts[c,3], Peter J. Weisberg[c,4], Carl Skinner[d,5], Jian Yang[c,3]

[a] Environmental Science and Management Department, Portland State University, PO Box 751, Portland, OR 97207, USA
[b] 3170 Highway 50 Suite #7, South Lake Tahoe, CA 96150, USA
[c] Department of Natural Resources and Environmental Science, University of Nevada, Reno, 1664 N. Virginia St., Mail Stop 186, Reno, NV 89557, USA
[d] Pacific Southwest Research Station, USDA Forest Service, 3644 Avtech Parkway, Redding, CA 96002, USA

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ABSTRACT

Fuel-reduction treatments are used extensively to reduce wildfire risk and restore forest diversity and function. In the near future, increasing regulation of carbon (C) emissions may force forest managers to balance the use of fuel treatments for reducing wildfire risk against an alternative goal of C sequestration. The objective of this study was to evaluate how long-term fuel treatments mitigate wildfires and affect forest C. For the Lake Tahoe Basin in the central Sierra Nevada, USA, fuel treatment efficiency was explored with a landscape-scale simulation model, LANDIS-II, using five fuel treatment scenarios and two (contemporary and potential future) fire regimes. Treatment scenarios included applying a combination of light (hand) and moderate (mechanical) forest thinning continuously through time and transitioning from these prescriptions to a more mid-seral thinning prescription, both on a 15 and 30 year rotation interval. In the last scenario, fuel treatments were isolated to around the lake shore (nearby urban settlement) to simulate a low investment alternative were future resources may be limited. Results indicated that the forest will remain a C sink regardless of treatment or fire regime simulated, due to the landscape legacy of historic logging. Achievement of a net C gain required decades with intensive treatment and depended on wildfire activity: Fuel treatments were more effective in a more active fire environment, where the interface between wildfires and treatment areas increased and caused net C gain earlier than as compared to our scenarios with less wildfire activity. Fuel treatments were most effective when continuously applied and strategically placed in high ignition areas. Treatment type and re-application interval were less influential at the landscape scale, but had notable effects on species dynamics within management units. Treatments created more diverse forest conditions by shifting dominance patterns to a more mixed conifer system, with a higher proportion of fire-tolerant species. We demonstrated that a small amount of wildfire on the landscape resulted in significant changes in the C pool, and that strategically placed fuel treatments substantially reduced wildfire risk, increased fire resiliency of the forest, and is beneficial for long-term C management. Implications for landscape management included consideration for prioritization of treatment areas and creating ideal re-entry schedules that meet logistic, safety, and conservation goals. In forests with a concentrated wildland urban interface, fuel treatments may be vital for ensuring human welfare and enhancing forest integrity in a fire-prone future.

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1. Introduction

Fuel-reduction (i.e., forest thinning) treatments are used extensively throughout the western US and worldwide to reduce hazardous surface and ladder fuels and restore forest structure to more fire resilient conditions (Agee and Skinner, 2005). The forests of the Sierra Nevada are of particular concern because fuel loads and density of small trees have exceeded known historic conditions (Parsons and DeBenedetti, 1979) and the wildland urban interface has increased (Radeloff et al., 2005; Syphard

* Corresponding author. Present address: Forestry Sciences Laboratory, Center for Forest Disturbance Science, USDA Forest Service, 320 Green Street, Athens, GA 30602, USA. Tel.: +1 706 559 4309.
E-mail addresses: elloudermilk@fs.fed.us (E.L. Loudermilk), alisonestanton@gmail.com (A. Stanton), rmschell@pdx.edu (R.M. Scheller), tdilts@cabnr.unr.edu (T.E. Dilts), pweisberg@cabnr.unr.edu (P.J. Weisberg), cskinner@fs.fed.us (C. Skinner), jyang@cabnr.unr.edu (J. Yang).
[1] Tel.: +1 415 990 2269.
[2] Tel.: +1 503 725 2497.
[3] Tel.: +1 775 784 6984.
[4] Tel.: +1 775 784 7573.
[5] Tel.: +1 530 226 2554.

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et al., 2007). As a result, recent severe wildfires often exceed estimates of historic severity (Westerling et al., 2006; Littell et al., 2009) and have destroyed homes and businesses and threatened urban centers (Radeloff et al., 2005; Safford et al., 2009). Applying fuel treatments has become an essential management tool for reducing wildfire intensity and severity in this region (Agee and Skinner, 2005; Schwilk et al., 2009; Syphard et al., 2011). The trade-offs among fuel treatments, labor costs to implement them, preserving wildlife habitat, and in the near future, regulation of carbon (C) emissions, are of concern (Calkin and Gebert, 2006; Pilliod et al., 2006; Scheller et al., 2011b; Campbell et al., 2012).

In particular, regulation of C emissions may force forest managers to balance the use of fuel treatments for reducing wildfire risk against goals to maintain or increase C sequestration (Hurteau et al., 2008). This will require consideration of the net balance between the immediate loss of C from live and detrital matter during fuels management (e.g., mechanical thinning and prescribed burning) against the long-term C sequestration potential associated with reduced C emissions from lower intensity wildfires (Hurteau et al., 2008; Scheller et al., 2011a). Previous research that explicitly study C dynamics have typically addressed only aboveground C stocks (e.g., Hurteau and North, 2009), although surface and soil C are important long-term C stocks as well (Johnson et al., 1997) and fluctuate in response to changes in live and detrital inputs (Scheller et al., 2011a; Karam et al., 2013). Although much of the live C during a severe wildfire is emitted, a portion is transferred to the detrital pool as coarse woody debris and surface C, and eventually to the soil C pools (Scheller et al., 2011a; Karam et al., 2013). The physical removal of C during thinning and how debris is handled after thinning (e.g., pile or prescribed burning) may influence these C flows as well (Murphy et al., 2006; Finkral and Evans, 2008; Hurteau et al., 2008; Nave et al., 2010), but only to the extent of area being treated and re-application interval. This study addresses above and belowground live C as well as soil and detrital C that when combined with effects from wildfire disturbance and forest thinning provide a more complete picture of C dynamics that influence sequestration patterns.

Properly balancing multiple landscape management objectives, including activity implementation (e.g., treatment location) and understanding feedbacks with ecosystem C dynamics (e.g., Daugherty and Fried, 2007; Rhodes and Baker, 2008; Schmidt et al., 2008), requires more information about their inherent trade-offs, and improved awareness of the opportunities for optimizing management at the landscape scale (Syphard et al., 2011). The strategic placement of fuel treatments is important for reducing landscape level wildfire spread and intensity (Finney et al., 2008; Schmidt et al., 2008) and therefore understanding where treatments may be most effective may be more important than the amount of area treated. For instance, wildfire-treatment intersection may be more likely if treatments are applied in areas of known high ignition potential (Thompson et al., 2013). The re-application timeline or rotation period is also of interest because more intensive treatments (e.g., mechanical vs. hand thinning) may have a longer effective period for reducing wildfire risk (e.g., Stephens et al., 2012b). Maintaining fuel treatments through time re-structures the landscape, creating a more fire-resistant forest, and maintains live C stocks by reducing C emissions from wildfire in the long run (Hurteau and North, 2009; North and Hurteau, 2011). Estimating the potential for a particular fuel treatment practice or regime to reduce wildfire risk or severity and alter ecosystem and C dynamics requires an assessment at the landscape level where the spatial arrangement of fuel treatments and the potential intersection with wildfires can be addressed (Syphard et al., 2011).

The objective of this study was to evaluate how long-term fuel treatments mitigate wildfires and affect forest C in the Lake Tahoe Basin, a conifer-dominated forest in the central Sierra Nevada, USA, that has experienced fire exclusion over the past 150 years (Beaty and Taylor, 2008).We used a landscape-scale simulation model of forest succession (Scheller et al., 2007), stochastic wildfire (Sturtevant et al., 2009), ecosystem C dynamics (Scheller et al., 2011a), and forest thinning (Syphard et al., 2011) to understand long-term effects of fuel treatments on wildfires, above and belowground C dynamics, as well as species and community structure. A multiple fuel treatment scenario design was used to examine the interactive effects of treatment application in terms of spatial arrangement and location, rotation period, and prescription type. We explored the effectiveness of fuel treatments using two fire regimes that contrast the contemporary fire regime with a more active fire environment that is forecast for the near future. Results are discussed in terms of long-term landscape implementation of fuel treatments and evaluating the potential for net C gain.

2. Methods

2.1. Study area

Our study area comprises approximately 85,000 ha of forested land in the Lake Tahoe Basin (LTB, Fig. 1). The climate is Mediterranean with a summer drought period; the basin topography and elevation range (ca. 1897–3320 m) control local temperature and precipitation patterns. Mean daily temperatures range from −6 to 24 °C and have an annual average temperature of 5 °C. Snowfall is the primary form of precipitation (50–150 cm annually), which occurs between October and May and snowpack persists into the summer dependent on elevation. Soils are classified as shallow Entisols or Inceptisols and the more developed soils are Alfisols. The substrate is mainly granite with ancient volcanic bedrock lining the north shore (Rogers, 1974). Tree species distribution in the LTB is controlled by elevation and precipitation (Barbour et al., 2002). The lower montane zone in the west Basin is primarily a mixed conifer forest consisting of up to six co-dominant species including white and red fir (*Abies concolor*, *Abies magnifica* A. Murr.), incense cedar (*Calocedrus decurrens* Torr.), and Jeffrey, sugar, and lodgepole pine (*Pinus jeffreyi* Grev. & Balf., *Pinus lambertiana* Dougl., *Pinus contorta* Dougl. ex. Loud.). The east side montane zone is dominated by Jeffrey pine, red fir, and/or white fir. The subalpine zone consists of whitebark pine (*Pinus albicaulis* Engelm.), western white pine (*Pinus monticola*. Dougl. ex D. Don), and mountain hemlock (*Tsuga mertensiana* (Bong.) Carr.).

Approximately two-thirds of the lower montane zone in the LTB was clearcut during the Comstock logging era beginning around 1870 and continuing through the beginning of the last century. Timber harvest and subsequent fire suppression has shifted forest age and size distribution from a characteristic old-growth canopy, with an open mid-story, to a denser forest of younger age-cohorts (<120 years old) and more closed mid-story (Barbour et al., 2002; Taylor, 2004).This shift has allowed surface and ladder forest fuels to accumulate and has increased wildfire risk (Beaty and Taylor, 2008). In addition, shade tolerant trees (e.g., white fir and incense cedar) have increased disproportionately over fire-adapted species like Jeffrey and sugar pine (Nagel and Taylor, 2005).

2.2. Model description and development

To address the disturbance feedbacks of fuel treatments and wildfires on coarse-scale forest and C dynamics, we used the Landscape Disturbance and Succession model, LANDIS-II (v.6.0). The LANDIS-II model has been used extensively for understanding ecosystem C dynamics (Scheller et al., 2011a, 2011c) and feedbacks associated with wildfire (Sturtevant et al., 2009) and fuel treatments (Syphard et al., 2011). LANDIS-II offers the flexibility