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Long-term effects of fuel treatments on aboveground biomass accumulation in ponderosa pine forests of the northern Rocky Mountains

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ABSTRACT

Fuel treatments in ponderosa pine forests of the northern Rocky Mountains are commonly used to modify fire behavior, but it is unclear how different fuel treatments impact the subsequent production and distribution of aboveground biomass, especially in the long term. This research evaluated aboveground biomass responses 23 years after treatment in two silvicultural installations with different cutting and underburning prescriptions in western Montana. The thinning installation included control (no treatment), thin/no burn, thin/spring burn, and thin/fall burn treatments. The shelterwood installation included control, cut/no burn, cut/wet burn, and cut/dry burn treatments. Across all fuel treatments in both the thinning and shelterwood installations, tree biomass had recovered to pre-harvest levels by 2015, or 23 years post-treatment. In the thinning, total aboveground and live-tree biomass were greatest in the control, but did not differ among the three thinned fuel treatments. Forest floor biomass was lower in the two burned treatments relative to the two unburned treatments. Seedling, vegetation, stump, and snag biomass did not differ among the four treatments. In the shelterwood, total aboveground and live-tree biomass were both greater in the unburned treatments relative to the burned treatments. Forest floor and snag biomass also tended to be lower in the burned treatments. Seedling, vegetation, and stump biomass were similar across all treatments. This research shows that tree biomass in ponderosa pine stands subjected to common fuels treatments can recover to pre-harvest levels in less than 23 years, while still exhibiting reduced stand densities that promote forest restoration objectives. Burgeoning biomass at the seedling layer suggests that additional understory treatments are necessary in order to abate ladder fuel development and sustain resistance to high-severity wildfire.

1. Introduction

In the western United States, many low-elevation, dry forest types have experienced substantial increases in forest biomass over the past century. For instance, between 1953 and 2012, net forest volume in the Intermountain West increased by 30 percent (Oswalt et al., 2014). This increase in biomass is primarily attributed to declines in logging activity and the rise of fire exclusion policies. Prior to European settlement, low-to-mixed severity fires burned western dry forest types at average intervals of 3–50 years (Hessburg and Agee, 2003; Fitzgerald, 2005). However, logging, grazing, and fire suppression have all contributed to interruptions in natural disturbance regimes (Pyne, 1982; Agee, 1993; Stephens and Ruth, 2005; van Wagtendonk, 2007; Naficy et al., 2010), with dry forest types burning less frequently than historically (Parks et al., 2015). It is estimated that of the 236 million acres in the West identified as forestlands, 67 million acres have been moderately or significantly altered by fire exclusion (USDA Forest Service, 2005).

Evaluation of carbon storage capacity in fire-prone landscapes is difficult because of the variable nature of fire and resulting effects (Loehman et al., 2014). An oft-cited inadvertent benefit of the suspension of natural disturbance regimes and increases in forest biomass has been a net gain in carbon sequestration throughout many of the dry forest types in the West, which has helped to offset fossil fuel emissions (Sohngen and Haynes, 1997; Houghton et al., 2000; Hurtt et al., 2002). However, as changing climate conditions result in longer and drier fire seasons, fire exclusion is becoming less feasible, and 100 years of fuel accumulation is resulting in fires of much higher severity, intensity, and magnitude than those historically present on the landscape (Westerling et al., 2006; Flannigan

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et al., 2013; van Mantgem et al., 2013). Carbon emitted from high-severity forest fires can be substantial, and in some years, even exceed regional annual carbon emissions from fossil fuels (Wiedinmyer and Neff, 2007; Dore et al., 2008). This transformation of a forest from a sink to a source is known as an offset reversal (Mignone et al., 2009). Recent studies suggest that fuel management treatments can prevent offset reversal in forests with low and mixed-severity fire regimes by reducing the high-severity wildfire hazard (Loehman et al., 2014).

Wildfire hazard is typically mitigated by applying a diverse set of silvicultural, mechanical, and prescribed fire strategies to alter the quantity and structure of forest fuel complexes, and thereby alter potential fire behavior (Graham et al., 2004). For instance, crown fire hazard is often addressed by reducing canopy density, removing small diameter ladder fuels, and increasing canopy base height (Graham et al., 1999; Keyes and O'Hara, 2002; Agee and Skinner, 2005; Fitzgerald, 2005; Reinhardt et al., 2008). Activity fuels produced by harvesting are typically treated by piling and burning, mastication or mulching, or broadcast burning (Agee and Skinner, 2005). While the effectiveness of these treatments on reducing subsequent fire severity is well documented (Kalies and Yocom Kent, 2016), uncertainties remain as to how these fuel treatments impact ecosystem biomass and whether or not the net amount of carbon released from fuel reduction treatments is less than that of potential wildfire emissions. There is increasing evidence that reducing wildfire severity, even at the cost of initial carbon reductions from thinning, will result in a more sustainable carbon sink over the long term (Hurteau et al., 2008; Hurteau and North, 2009; Amiro et al., 2010; Dore et al., 2010). For example, Hurteau et al. (2008) found that thinning prior to wildfire occurrence could reduce carbon emissions from live tree biomass by as much as 98%. As wildfire is an inevitability across much of the western landscape, implications of these treatments for offsetting carbon emissions may be substantial.

In addition to reducing emissions from high-severity wildfires, fuel treatments may help restore attributes of pre-settlement forest structure. There is evidence that the fewer large trees present in western forests prior to European settlement stored more carbon than the abundance of smaller trees that currently exist (Fellows and Goulden, 2008) and that large trees both fix and store more carbon relative to small trees (Stephenson et al., 2014). By reducing competition for water, nutrients, and light, residual trees may experience increased photosynthetic rates after harvest, increasing the amount of carbon sequestered per individual tree (Feeney et al., 1998; Skov et al., 2004; Sala et al., 2005; Dore et al., 2010). Increased vigor of individual trees may also contribute to maintaining long-term live biomass carbon sinks in the face of increasing occurrences of drought and other disturbances such as insects and disease (Larsson et al., 1983; Skov et al., 2004; Hood et al., 2016).

It is estimated that of the 6.9 billion bone dry tons of standing timber volume in the 15 western states of the United States, removal of approximately 2 billion bone dry tons (almost 30%) is required from forests with historically low and mixed-severity fire regimes in order to restore pre-settlement biomass quantities (USDA Forest Service, 2005). However, there is uncertainty regarding where and how this biomass should be removed to balance carbon storage objectives with ecological restoration objectives. Moreover, it is unclear how biomass will respond to these treatments in the long-term, as very few studies have examined biomass trends over periods longer than 3 years post-treatment.

This study evaluated aboveground biomass in a ponderosa pine (*Pinus ponderosa* Lawson & C. Lawson var. *ponderosa* C. Lawson)/ Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco var. *glauca* (Beissn.)) forest in western Montana 23 years after application of several common fuel reduction treatments. Our primary objective was to determine how treatments impact each of the different components of aboveground biomass, and to describe the development of these components over the 23-year post-treatment period. We hypothesized that 23 years after treatment (1) live tree biomass would remain lower in all fuel reduction treatments relative to pre-treatment biomass levels, while (2) forest floor biomass and understory vegetation biomass would recover since time of treatment and be consistent across all treatments. We also predicted that (3) seedling biomass would be greatest in the thinning without prescribed fire treatments, and that (4) snag biomass would be greatest in the untreated control. Finally, we expected (5) total aboveground biomass in each of the fuel reduction treatments would continue to be lower than the control 23 years after treatment. This research is directed at helping managers anticipate the long-term effects of fuel reduction treatments on the structure of aboveground biomass in northern Rocky Mountain ponderosa pine forests.

2. Methods

2.1. Study site

Research was conducted at the Lick Creek Demonstration/ Research Forest (hereafter: Lick Creek) on the Darby Ranger District of the Bitterroot National Forest in southwestern Montana (46°5′N, 114°15′W) (Fig. 1a). Forest management in portions of the Lick Creek drainage began in 1909, and the area has a long history of documented research studies (Smith and Arno, 1999). The site is semi-arid, with an estimated average annual temperature of 7 °C and precipitation of 400 mm, with about 30% of this annual precipitation falling as snow (Gruell et al., 1982; DeLuca and Zouhar, 2000). Elevations within Lick Creek range from approximately 1300 to 1500 m, with slopes primarily ranging from 0 to 30 percent (Menakis, 1994). Soils are relatively shallow or moderately deep, and are classified as Elkner Gravelly Loam, coarse-loamy, mixed, frigid Typic Cryochrepts, with highly weathered granite parent material (DeLuca and Zouhar, 2000).

Overstory vegetation consists principally of ponderosa pine and intermittent Douglas-fir, with grand fir (*Abies grandis* (Douglas ex D. Don) Lindl.), subalpine fir (*Abies lasiocarpa* (Hook.) Nutt. var. *lasiocarpa*), and lodgepole pine (*Pinus contorta* Douglas ex Loudon var. *latifolia* Engelm. ex S. Watson) occasionally present. Habitat types as classified by Pfister et al. (1997) within the drainage are Douglas-fir/snowberry (*Symphoricarpos albus* (L.) S.F. Blake) and Douglas-fir/pinegrass (*Calamagrostis rubescens* Buckley) located on the southerly aspects, and Douglas-fir/dwarf huckleberry (*Vaccinium caespitosum* Michx.), Douglas-fir/blue huckleberry (*Vaccinium globulare* Douglas ex Torr.), Douglas-fir/twinflower (*Linnaea borealis* L. subsp. *americana* (Forbes) Hultén ex R.T. Clausen) and grand fir/twinflower on the northwest aspects (Menakis, 1994).

2.2. Experimental design

Two installations were examined: a commercial thinning and a retention shelterwood (Table 1) that were concurrently established as independent studies, each with a complete block design and subsampling. Each installation has four treatments replicated three times for twelve experimental units, with 12 permanent plots per unit. The treated units were randomly assigned, but the control (no treatment) units had non-random placement due to logistical reasons for the prescribed burns. We refer to the control units as "untreated" and the harvested/burned units collectively as "treated." Non-permanent inventory plots measured prior to unit designation provide general pre-treatment stand structure and composition. Pre-treatment fuels and vegetation were measured in 1991