Long-term Assessment of the Efficacy of Prescribed Burning and Mechanical Cutting for Restoration of Whitebark Pine

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ABSTRACT

Whitebark pine is declining across most of its range due to the combined effects of an invasive pathogen, episodic native insect outbreaks, climate-change-induced increases in wildfire frequency, and successional replacement due to fire suppression. Prescribed burning and mechanical cuttings have been proposed as primary strategies for restoration. However, there is limited information on the efficacy and effects of these treatments, and projects that have been evaluated show highly variable results, suggesting that monitoring is a priority need. We used a 15-year, replicated before-after-control-impact study to assess the effects of prescribed burning and mechanical cuttings on mortality, seedling density change, and basal area change for competing conifers in the northern Rocky Mountains of the United States. Whitebark pine mortality (plot percentage) was about 20% higher for prescribed burning alone and prescribed burning and mechanical cutting than control plots. Seedling density change (ind./ha) was 1% lower and 14% higher than control plots for prescribed burning alone and prescribed burning and mechanical cutting, respectively. Basal area change (m^2/ha) of *Abies lasiocarpa* was 61% and 98% lower than control plots for prescribed burning alone and prescribed burning and mechanical cutting, respectively. Since the implementation of this experiment in the mid-90s, whitebark pine communities have shown a significant increment in mortality of mature trees and reduced natural regeneration in addition to the treatments effect. These results indicate that active management is an effective strategy to mitigate the effect of current threats, where trade-off's include promoting natural regeneration at the cost of greater tree mortality.

INTRODUCTION

Whitebark pine (*Pinus albicaulis*), an ecologically important tree species of high-elevation ecosystems of western North America, is declining across most of its range due to the combined effects of an invasive pathogen (white pine blister rust; *Cronartium ribicola*), episodic native insect (mountain pine beetle; *Dendroctonus ponderosae*) outbreaks, climate-change-induced increases in wildfire frequency and severity (Keane and Arno 1993; Westerling et al. 2006) as well as successional replacement as a result of a century of fire suppression in the mesic part of its distribution. Concern over these threats has led to a petition to list whitebark pine as a threatened species under the US Endangered Species Act (FWS 2021), the designation as a species at-risk under the Canadian Endangered Species Act (NRDC 2008), and an increase in research and management activities. Despite a growing understanding and widespread agreement on the need for conservation and restoration (Keane et al. 2012), there is little information on the species' response to management actions. Specifically, the extent to which prescribed fire and mechanical cuttings are effective for meeting restoration objectives. To assess long term effects of prescribed burning and mechanical cuttings on whitebark pine forests, we analyzed data collected over 15 years in the Bitterroot Mountains, Montana, USA.

Prescribed burning and mechanical cutting are included as key activities in the Range-Wide Restoration Strategy for Whitebark Pine (Keane et al. 2012) and in the National Whitebark Pine Restoration Plan. The goals of these treatments are to promote diverse age-class structure, reduce competing vegetation, increase the vigor of mature whitebark trees, encourage natural regeneration, and reduce mountain pine beetle hazard (Keane et al. 2012). Nonetheless, there is still uncertainty on the ecological viability of these restoration activities and their potential outcomes (Maher et al. 2018; Keane 2018; Tomback et al *in review*). Currently, few mechanical cuttings, and even fewer prescribed burns, have been monitored for their ecological effects, and for the ones that have, findings are mixed, suggesting that additional monitoring is a priority need. Also, because effects of treatments on seedling recruitment are notoriously difficult to study due to high spatial and temporal variability in high-elevation seedling establishment driven by decadal-scale oscillations in climate (Youngblut and Luckman 2013), determining regeneration responses requires sampling over long timeframes with standardized methods capable of capturing an effect. Here we took advantage of the only existing long-term before-after-control-impact (BACI) replicated study, that we are aware of, on the efficacy and ecological effects of mechanical cuttings and prescribed burns in whitebark pine forests to ask questions about treatment efficacy and effects. Our specific research question is: What is the magnitude of difference among treatments (prescribed burn, prescribed burn and mechanical cutting, and untreated control) in whitebark pine mortality, abundance, and regeneration, as well as in the abundance of competitor conifer species (*Abies lasiocarpa, Picea engelmannii, Pinus contorta*), over a 15-year period?

MATERIALS AND METHODS

Experimental design: This study is part of an on-going long-term monitoring project, "Restoring Whitebark Pine Communities" (Keane and Parsons 2010b), that was designed to test the effects of prescribed burning and mechanical cutting on whitebark pine ecosystems. The study included a combination of experimental silvicultural treatments and prescribed burning with or without fuel bed enhancement. The study was implemented at five sites (Bear Overlook, Beaver Ridge, Coyote Meadows, Musgrove, and Smith Creek) in the northern Rocky Mountains of the United States. We analyzed data from just one of the five sites, Bear Overlook, because it was the only site that met the following experimental conditions: (1) had treated areas and controls sampled in the 15th year after treatment implementation, and (2) had been unaffected by post-treatment wildfire events.

At the Bear Overlook site, ten 0.04 ha plots were installed at each of three treatment units (prescribed burning alone, prescribed burning and mechanical cutting, and untreated control). In 1996, vegetation was sampled; live trees above 12 cm were tagged and species, DBH, tree height, height to crown base, and health were recorded. The same measurements were also recorded on all live trees less than 12 cm DBH (in 2.5 cm DBH classes) and greater than 1.37 m tall (saplings). *P. albicaulis* seedlings (trees less than 1.37 m tall) were counted within a 125 m^2 circular plot nested within each 0.04 ha plot. In 1999, a low-intensity underburn was implemented in both units that included prescribed burning. In one of these units, prior to the burn, all trees from competing species were harvested. Vegetation was sampled again the year after treatment implementation, and every 5 years after that. For the purposes of this study, we analyzed the 15-year post-treatment data to test for responses since the last assessment (Keane and Parsons 2010b).

To assess the effect of prescribed burning alone and in combination with mechanical cutting on whitebark pine mortality (proportion of live trees sampled pre-treatment that were dead by the 15th year post-treatment), we calculated abundance (relative change in basal area pre-treatment to last post-treatment sample year), regeneration (relative change in seedling density pre-treatment to last post-treatment sample year), and abundance (change in basal area pre-treatment to last post-treatment sample year) of competing conifers, and used non-parametric Kruskal-Wallis tests to determine statistical significance for each response variable.

RESULTS

Treated stands had 80% and 78% whitebark pine mortality (prescribed burning alone and prescribed burning and mechanical cutting, respectively), about 20% higher than the mortality in the untreated stand. However, this trend was not statistically significant ($\chi^2 = 2.34$, df = 2, $\rho = 0.31$, figure 1A). Over the 15-year period in the control stand, *A. lasiocarpa*, *P. contorta*, and *P. engelmannii* increased in basal area by 77% (± 28 SE), 7% (± 18 SE), and 10% (± 4 SE), respectively,

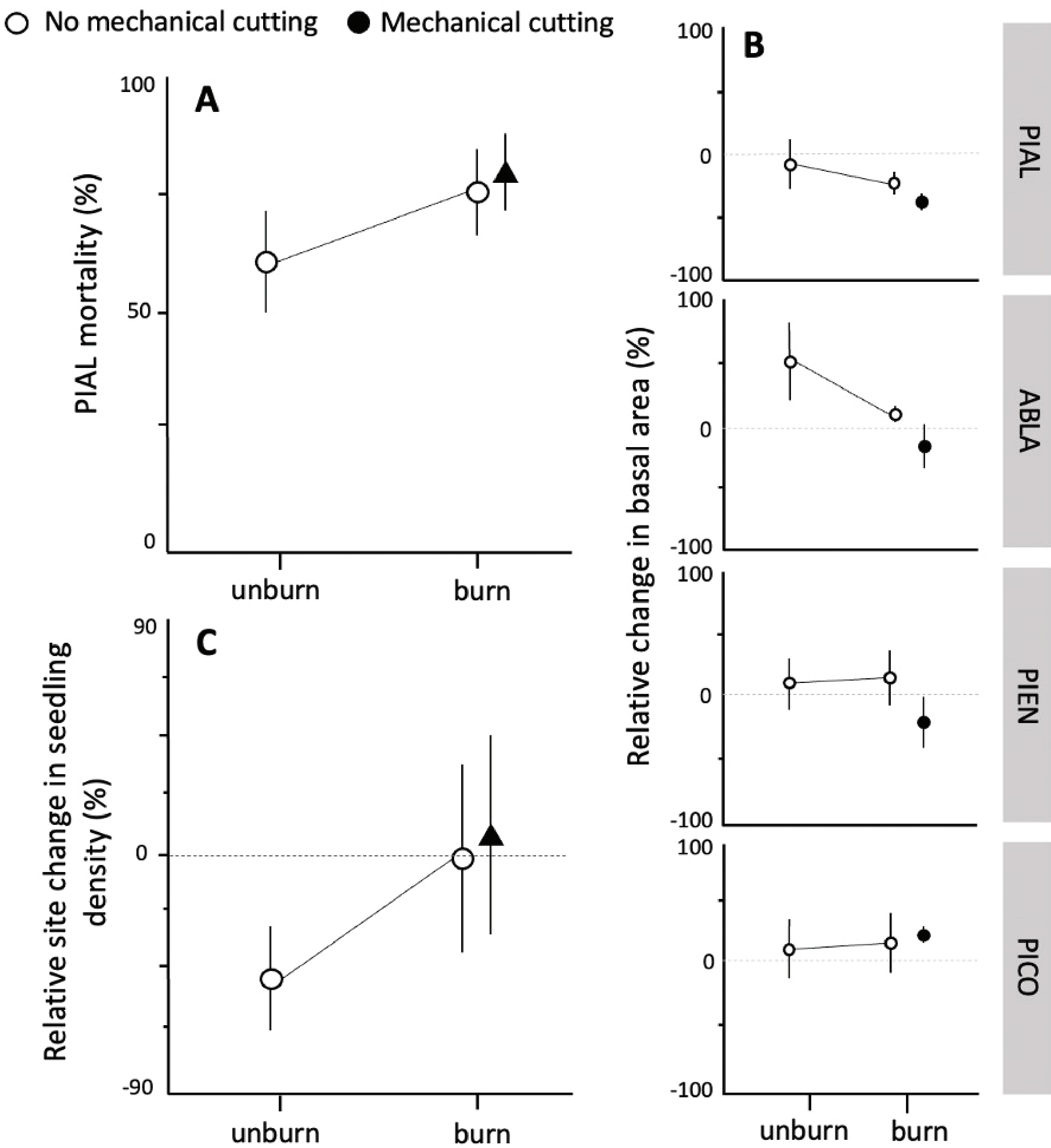

Figure 1. PEffect of prescribed burning (x-axis) and mechanical cutting (closed symbols, harvested; open symbols, not harvested) on (A) mean (± SE) adult whitebark pine tree mortality (% over the 15 year period); (B) mean (± SE) relative change (% change pre to post treatment) in live tree basal area (m^2/ha) of *Pinus albicaulis* and three shade-tolerant conifer species; and (C) mean (± SE) relative change (% change pre to post treatment) in whitebark pine seedling density. PIAL = *Pinus albicaulis*, ABLA = *Abies lasiocarpa*, PIEN = *Picea engelmannii*, PICO = *Pinus contorta*.

while *P. albicaulis* decreased by 8% (± 20 SE) from pre-treatment levels. In comparison, in the prescribed burning alone stand, *A. lasiocarpa*, *P. contorta*, and *P. engelmannii* increased in basal area by 16% (± 7 SE), 13% (± 21 SE), and 15% (± 23 SE), respectively, while whitebark decreased by 27% (± 13 SE). In the prescribed burning and mechanical cutting treatment, basal area of *A. lasiocarpa* and *P. engelmannii* declined by 21% (± 25 SE), and 23% (± 21 SE), respectively, and *P. contorta* increased by 18% (± 8 SE), while whitebark decreased by 45% (± 6.1 SE).

The observed changes in basal area (pre to 15 years post treatment) were significantly different among treatments only for *A. lasiocarpa* (χ^2 = 10.29, df = 2, ρ = 0.0058 figure 1B). There were no significant differences among treatments for *P. contorta* (ρ =0.27), *P. engelmannii* (ρ =0.33), or *P. albicaulis* (ρ =0.31).

In the control, seedling density declined by 37% (± 19 SE). In comparison, in the prescribed burning only treatment, seedling density declined by only 1% (± 31 SE) and, in the prescribed burning and mechanical cutting treatment, it increased by 14% (± 37SE). However, the change in seedling density pre to 15-years post treatment was not significantly different among treatments (χ^2 = 2.34, df = 2, ρ = 0.55) (figure 1C).

DISCUSSION

Given increasing concern about declines in whitebark pine across its range (Loehman et al. 2018), there is a corresponding need to examine effects of restoration and management treatments being implemented to mitigate current threats. Our results suggest that the combined effect of prescribed burning and mechanical cutting reduced competing conifers (*A. lasiocarpa* and *P. engelmannii*) and released whitebark pine seedlings. However, this result came at the cost of higher mortality of potentially cone-bearing adult trees. This setback supports other observations that fire may adversely affect whitebark pine (Nelson and Keville 2018, Keane 2018), even at relatively low levels of bole scorch (Hood et al. 2008) over the 15 years of this study.

One limitation that could affect inference from our study is lack of replication. We assessed only one site. Although the original study included five sites, four were disturbed by post-treatment wildfire. Furthermore, only two of the original sites had data collected from both treated areas and controls by the 15th year after treatment implementation. The high probability of disturbance and other chance events impacting project sites, coupled with high variability in both treatment prescriptions and their effects (Maher et al. 2018), suggest the need to include a much larger number of replicates in assessments of treatment effects. Given that, the data needs for inference may be too large for any one administrative unit or research project alone. Consideration should be given to developing a large-scale long-term monitoring network to improve understanding of the efficacy and effects of restoration treatments in whitebark pine ecosystems.

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