Slash Compression Treatment Reduced Tree Mortality from Prescribed Fire in Southwestern Ponderosa Pine

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ABSTRACT: *Intensive thinning prescriptions intended to restore historic forest structure have produced heavy broadcast slash fuel loads in northwestern Arizona, sometimes leading to high tree mortality following prescribed burning. Mechanical slash compression with a D-6 bulldozer to reduce the severity of fire effects on residual trees was evaluated. Ten of 42 measured trees (24%) died within 2 years after burning of broadcast slash, and crown scorch of trees without slash compression treatment averaged 26%. In contrast, no trees died after burning of compressed slash and crown scorch averaged <3%, even though the total fuel loading was indistinguishable from the broadcast slash treatment. The practice of raking fuels away from the boles of old-growth trees also contributed to reduced scorch as compared to younger, unraked trees. Slash compression is a viable method of reducing mortality, offering ecological and economical tradeoffs. Benefits include the ability to reduce large quantities of slash, safeguarding old-growth tree survival while rapidly achieving open forest structure. Costs include paying for equipment operation as well as the possibility of damage to soils or plants. West. J. Appl. For. 19(3):149–153.*

Key Words: Ponderosa pine, Arizona, burning, fuel treatment, ecological restoration.

Thinning and prescribed burning are widely advocated to reduce hazardous fuels and restore historic forest conditions in ponderosa pine (*Pinus ponderosa*) forests (Lynch et al. 2000, Covington 2000). Even when large trees are preferentially retained, thinning residues substantially increase woody fuel loadings (Fulé et al. 2002a). There are tradeoffs among the common methods of slash disposal. Slash removal takes foliar nutrients off site and is not economically feasible in remote areas of the Southwest. Piling concentrates fuels in pile locations, reducing the general level of heat and increasing the window of safety for prescribed burning. Piles are often burned under snow in the winter. However, soils are severely heated under piles, facilitating establishment of exotic plants (Korb 2001). Machinery used for piling can scrape and compact soils and damage understory plants. Broadcast slash burning retains nutrient-rich ash on the site and disperses soil heating. However, burning of broadcast slash can result in excessive mortality of residual trees because of high fire intensities caused by "red" slash fuels (dried needles or leaves).

Crown scorch and bole char are among the leading causes of long-term mortality in ponderosa pine (Wyant et al. 1986, Ryan 1982). Orozco and Carrillo (1993) found that burning red slash during periods when heavy fuels were saturated and duff was moist reduced fire intensities by limiting fuel consumption to 1- and 10-hour fuels. This in turn reduced crown scorch and prevented cambial and root damage resulting from deep smoldering fire. Dormant season burns have also been found to greatly reduce mortality even if large percentages of individual crowns are scorched (Harrington 1987).

A landscape-scale forest restoration project was implemented at Mt. Trumbull, in northwestern Arizona, beginning in 1995 (Moore et al. 1999). The Bureau of Land Management, in cooperation with Northern Arizona University and the Arizona Game and Fish Department, has carried out thinning followed by prescribed burning. Burns were conducted during the dormant season and fuels were

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raked away from the boles of all of the old-growth trees to prevent cambial girdling (Sackett et al. 1996) but several fires still resulted in unacceptable levels of mortality, primarily due to crown consumption and/or scorch. In this study, we tested a slash compression treatment using a bulldozer to reduce mortality from prescribed burns. We hypothesized that slash compression would reduce flame lengths and fire intensity, thereby reducing prescribed fire mortality caused by crown scorch.

Methods

The study site is located near Mt. Trumbull on the Bureau of Land Management's (BLM) Arizona Strip District, within the Grand Canyon-Parashant National Monument (lat. 36°22′ N, lon. 113°7′ W). Dominant trees were ponderosa pine and Gambel oak (*Quercus gambelii*), with scattered pinyon pine (*Pinus edulis*), New Mexican locust (*Robinia neomexicana*), Utah juniper (*Juniperous osteosperma*), and numerous shrub species. Soils are derived from volcanic parent materials. Annual precipitation averages 50.5 cm and occurs primarily in the winter as snow and during the summer monsoon from Jul. to Sept. Prior to European settlement in 1870, surface fires were common, with a mean interval of 5 to 7 years, similar to most other southwestern ponderosa forests (Moore et al. 1999).

Control (standard burning of broadcast slash) and slash compression treatment areas, approximately 4 ha each, were selected in a thinned stand. Slope averaged 13% in the control and 18% in the treatment areas. All old-growth (pre-1870) ponderosa pine trees were retained. In addition, approximately three younger (post-1870) trees were retained within a 9- to 18-m radius of each snag or stump that provided evidence of a dead pre-1870 tree. The purpose of this thinning prescription was to provide a close match in forest density and spatial pattern to the structure that was present before fire exclusion (Covington et al. 1997, Fulé et al. 2001). Species other than ponderosa pine were not thinned. Prior to thinning, the stand averaged 880 trees/ha with basal area 30.1 m^2ha. Ponderosa pine made up 84% of basal area, Gambel oak made up 13%, and pinyon and juniper comprised the remainder. Stand structure has not yet been remeasured following treatment. However, similar treatments in an adjacent stand reduced forest density by 67% and basal area by 47% (Waltz et al. 2003).

Commercial thinning of merchantable timber had been conducted in the slash treatment and control areas in 1998–1999, leaving broadcast slash. After the commercial thin, excess submerchantable trees, <25 cm diameter at breast height (dbh), were felled, lopped and scattered as slash. Forest floor material was raked approximately 0.5 to 1 m away from the boles of all old-growth trees in both treatment areas to protect old trees from cambial girdling (Sackett et al. 1996). The purpose of the raking was to remove the bulk of fuels that could create severe heat due to smoldering combustion, but the raked areas were not cleared to mineral soil.

We selected individual ponderosa pine trees (focal trees) to serve as plot centers for fuel load estimates prior to broadcast burning. Focal trees were divided into two categories, old-growth trees (pre-1870, the time of European settlement and fire exclusion) and post-1870 trees. Old-growth trees were defined as mature ponderosa pines with characteristic yellow bark and rounded crowns (Figure 1). All the old-growth trees in each of the treatment and control areas were selected as focal trees ($N = 22$ in the slash compression treatment and $N = 19$ in the control). Because the density of the younger, post-1870 trees was higher than the density of old-growth trees, younger trees ($N = 20$) were selected in each of the treatment and control areas by randomly choosing 20% of the post-1870 trees.

With the focal tree serving as plot center, three 6.1-m fuel transects were extended from the base of the tree along the 0°, 120°, and 240° azimuths. Fuel loads were measured using planar transects (Brown 1974) with coefficients developed for southwestern ponderosa pine (Sackett 1980). Fuels were tallied according to established time lags required to change the moisture content of the fuel (Brown 1974). Fuels were classified as1-hour (0–0.6 cm diameter), 10-hour (0.7–2.5 cm diameter), 100-hour (2.6–7.6 cm diameter) and 1,000-hour (>7.6 cm diameter). Within each

Figure 1. Broadcast slash surrounding this pre-1870 tree was compacted with a D-6 bulldozer prior to burning; all trees in the slash compression treatment survived the fire.

transect, 1-hour, 10-hour, and 100-hour fuels were tallied within alternate 0.61-m increments. The purpose of the alternating tally increments was to capture fuel loads at different distances from the focal tree boles. One-thousand-hour fuels were tallied along the entire transect. Slash depths and forest floor depths were measured at 0.3, 1.5, 4.6, and 6.1 m along each transect. Slope, aspect, total height, ground to live crown height, crown radius, and dbh were recorded for each focal tree.

In the slash compression treatment, a D-6 bulldozer was driven over the cured slash to break down the vertical arrangement. Each unit area of the forest floor where slash was present was driven over approximately once, except where it was necessary to backup to maneuver the bulldozer between the trees. We did not remeasure fuels after compression, because the planar transect method is designed to measure woody fuels laying on or above the forest floor (Brown 1974). The compaction of fuels by the bulldozer, pushing some woody material into the forest floor, would have lead to a false impression of reduced fuels if measured by a planar transect, when in fact none of the fuels were removed. By measuring fuels after thinning and raking but before slash compression, we were able to assess whether fuel loads were similar in control and treatment areas.

Burning was carried out on Apr. 3, 2000, with a combination of backing fire and short (3–4.5 m) strip headfires. Both treatments were categorized as fire behavior fuel model 11 (light logging slash). The temperature ranged from 15–21 °C. Relative humidity ranged from 23 to 28%. Winds were 0–6 km/hr from the west. Average flame lengths were 0.6 m in the slash compression treatment, 0.6 m in the broadcast slash. Average maximum flame lengths were 1.1 m in the slash compression treatment and 1.3 m in the broadcast slash. Different observers in each treatment area measured the flame lengths.

Focal trees were remeasured during the summer of 2001 and again in the winter of 2002. Tree condition—live, declining, or dead—was observed. Bole char heights, crown scorch heights, and the volume of crown scorch were also measured.

Since the focal trees were located within geographically distinct treatment areas, the treatments could not be randomly assigned and the trees are pseudoreplicates rather than independent experimental units (Hurlbert 1984). This is a common issue in fire studies, because experimental creation of small interspersed plots of different burning treatments is often logistically impossible (van Mantgem et al. 2001), so cause-and-effect relationships cannot be inferred in a statistical sense. However, within the constraints of this study we carefully matched trees and sites and measured variables with clear causal links: preburning fuels and postburning scorch, char, and mortality.

Variables were tested for conformity with analysis of variance (ANOVA) assumptions and were square-root or natural-log transformed where necessary. Results were compared with two-way ANOVA tests on treatment and tree category ($\alpha = 0.05$). Multivariate ANOVA was used for the suite of intercorrelated woody fuel variables. Tukey's posthoc tests were then conducted to compare treatments separately on old-growth and post-1870 trees.

Results

Before burning, tree diameter and total height measurements were not significantly different between treatment sites before burning, although pre-1870 trees were significantly larger than the younger trees (Table 1). However, the ground-to-live-crown distances were indistinguishable between treatments and tree categories. Lighter woody fuels (1 to 100 h) were relatively similar across treatments and tree categories, except that the 10-hour fuels were significantly heavier below post-1870 trees in both treatments. Woody fuel loading was highest in the largest size class (1,000 h) and ranged from 34% to 70% higher under post-1870 trees than pre-1870 trees. Average forest floor depths did not differ by treatment or tree category, but slash depths were greater under post-1870 trees (Table 1).

The broadcast burn resulted in high mortality, with 24% of all focal trees dying by the winter of 2002 (Table 2). Mortality by tree category in the broadcast burn was 14% for old-growth trees (3 of 22) and 35% for post-1870 trees (7 of 20). In contrast, no trees died in the slash compression treatment in the first two growing seasons following burning (Table 2).

The weighted average of crown volume scorched in the broadcast burn was 25.7%, with significantly higher scorch

Table 1. Tree characteristics and fuel loading for the control and mechanical slash compression treatment after thinning at Mt. Trumbull, Arizona. Trees were categorized as old-growth (predating 1870, the date of European settlement and onset of fire exclusion) and post-1870. Means are followed by standard errors (in parentheses).[a]

Treatment/tree category	*N*	Dbh (cm)	Ground to live crown (m)	Height	1-hr fuel loading (Mg/ha)	10-hr fuel loading (Mg/ha)	100-hr fuel loading (Mg/ha)	1,000-hr fuel loading (Mg/ha)	Total fuel loading (Mg/ha)	Forest floor depth (cm)	Slash depth (cm)
Control/pre-1870	22	68.5a (2.2)	7.8a (0.4)	21.7a (0.8)	1.0a (0.1)	4.4a (0.4)	4.1a (0.5)	47.5a (4.2)	57.0a (4.3)	6.6a (0.5)	5.9a (0.6)
Control/post-1870	20	33.5b (1.1)	7.4a (0.4)	17.2b (0.5)	1.4a (0.2)	7.1b (0.8)	5.1a (0.7)	80.6b (12.1)	94.2b (12.3)	6.4a (0.4)	8.7ab (1.0)
Slash compression/ pre-1870	19	68.8a (3.4)	7.6a (0.6)	23.7a (0.9)	0.8b (0.1)	4.9a (0.9)	4.5a (1.0)	51.6ab (4.1)	61.8a (5.6)	7.0a (0.6)	5.7a (0.7)
Slash compression/ post-1870	20	36.8b (1.1)	7.9a (0.7)	18.3b (0.6)	1.3a (0.1)	7.5b (0.9)	6.3a (0.9)	69.3ab (8.9)	84.4ab (8.8)	5.8a (0.3)	11.2bc (1.4)

[a] Means in columns followed by different letters differ significantly, $\alpha = 0.05$.

Table 2. Fire effects on old-growth (pre-1870) and younger (post-1870) trees in the control and mechanical slash compression treatments. Means are followed by standard errors (in parentheses).[a]

Treatment/tree category	N	Char max (m)	Average min scorch height (m)	Average max scorch height (m)	Scorch (% crown vol)	Mortality after two growing seasons (%)
Control/pre-1870	22	0.2a (0.2)	1.6a (0.5)	1.8a (0.5)	14.0a (5.8)	14
Control/post-1870	20	0.9a (0.2)	2.6a (0.5)	3.1a (0.5)	38.6b (9.6)	35
Slash compression/ pre-1870	19	0.1a (0.1)	0.5a (0.2)	0.5a (0.2)	0.6a (0.3)	0
Slash compression/ post-1870	20	0.6a (0.2)	0.4a (0.2)	0.5a (0.3)	2.4a (1.3)	0

[a] Means in columns followed by different letters differ significantly, $\alpha = 0.05$.

(38.6%) in post-1870 trees (Table 2). In contrast, the average crown volume scorched was <3% in the slash compression treatment. Maximum scorch heights exceeded 9 m in the broadcast burn and averaged 3.1 m on post-1870 trees, as opposed to maximum heights of 3.1 m in the compression treatment and average values of 0.5 m. Maximum bole char was not significantly different among treatments (Table 2).

Discussion

Fuel loads and tree characteristics were essentially the same in both treatment and control areas after the thinning and fuel raking activities were completed, but the slash compression treatment was associated with a major reduction in fire severity: broadcast slash burning resulted in >25% tree mortality, in striking contrast to zero mortality in the slash compression treatment. Trees in the broadcast burn also had greater scorch heights and volume of scorched canopy.

The difference in fire effects suggests that fire-caused mortality may be influenced more by the vertical arrangement of the uncompacted slash than simply by gross fuel quantity. A simple mechanism would be that higher fire intensity in well-aerated cured fine fuels could have facilitated convection into the canopies of residual trees, resulting in high crown scorch. When vertical fuel arrangement was decreased in the slash compaction treatment, crown scorch was greatly reduced. However, although fire effects differed greatly between the two areas, fire line observers recorded identical flame length measurements. Since crown scorch is directly related to flame length (Agee 1993), the discrepancy between visual estimates and postfire scorch measurements indicates that periodic observations of flame length may be inadequate to develop a meaningful assessment of fire behavior. The fact that two different observers recorded data on the two study areas may have contributed to inconsistency.

In northern Arizona, the recommendation to rake fuels away from the boles of old-growth ponderosa pine trees arose in response to high mortality from cambial girdling at the Chimney Spring Interval Burning study site in northern Arizona (Sackett et al. 1996). Sackett et al. (1996) and Covington et al. (1997) found that cambial temperatures measured with thermocouples remained below lethal levels when fuels were raked away. In contrast, Swezy and Agee (1991) suggested that raking might harm vulnerable shallow roots by piling additional fuels on the rooting zone. In the present study, where raking occurred around old-growth trees in both the broadcast burn and the slash compression treatments, woody fuel and forest floor depths tended to be lower under the pre-1870 trees (Table 1). No old-growth trees died after the slash compression, and the old-growth mortality was only 40% that of younger trees in the broadcast burn. These results suggest that old trees received some benefit from raking, although 14% still died in the broadcast burn. Longer term data were presented by Kolb et al. (2001), indicating that no old-growth trees died as a result of prescribed burning in a study near Chimney Spring, AZ, when fuels were removed.

Managers should be aware, however, that tree mortality following burning is not a simple issue. High mortality was encountered after burning raked old-growth trees on shallow lava soils at Mt. Trumbull (Fulé et al. 2002b), while relatively low mortality occurred after burning unraked old-growth trees on limestone soils at Grand Canyon National Park (Kaufmann and Covington 2001).

Mechanical slash compression is a viable slash treatment for most high-intensity forest thinning operations in the Southwest. It will increase the total cost of the treatments by adding the cost of machine and operator time. There may be some undesirable ecological effects associated with equipment operation, such as additional soil disturbance (Korb et al. in press). These effects were not addressed in our study, although no increase in exotic species on the slash compression site was noted (P.Z. Fulé, personal observation, 2002). Weighed against these costs, however, is the fact that many forest restoration projects are explicitly aimed at conserving rare ecological elements such as old-growth trees. In these circumstances, slash compression may be a relatively economical alternative, especially as compared to more-intensive methods such as piling or complete removal.

Managers may choose to carry out intensive, single-entry forest restoration treatments because they can rapidly reduce fuel hazards (Fulé et al. 2001) and restore herbaceous production (Covington et al. 1997), tree growth (Feeney et al. 1998), and other desirable stand characteristics. A negative consequence of rapid treatment is the increase in short-term fuel loading, much of it loosely arranged volatile red slash, increasing the potential for severe fire effects.

Slash treatment alternatives such as mechanical compression will become more important to land managers because of the intensifying push to improve forest health and reduce fire hazard on larger and larger acreages of western lands over short periods of time.

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