Reintroducing Fire in Regenerated Dry Forests Following Stand-Replacing Wildfire[1]

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Abstract:

Prescribed fire use may be effective for increasing fire resilience in young coniferous forests by reducing surface fuels, modifying overstory stand structure, and promoting development of large trees of fire resistant species. Questions remain, however, about when and how to reintroduce fire in regenerated forests, and to what end. We studied the effects of spring prescribed fires on stand structure and canopy fuel properties in 25- to 34-year old ponderosa pine forest that was planted following the Entiat wildfire in 1970. Six adjacent units were ignited over the course of four days within a 256-acre, south-facing management unit in the Preston Creek drainage, near Entiat, Washington. Fire effects were assessed on a grid of 264 small (0.014 acre) plots, of which 219 (83%) contained at least one tree. Fires reduced mean tree density from 426 to 280 trees per acre and reduced mean stand basal area from 47 to 38 ft^2/acre. Fires also modified canopy fuels, raising mean canopy base heights from 1.0 to 6.3 feet and reducing canopy bulk density from 0.0064 to 0.0061 lbs/ft^3. Fire behavior and fire effects were heterogeneous within treatment units, however, and local fire severity was positively correlated with local stand basal area. Tree mortality probabilities declined with increasing tree diameter for all species. For any given diameter, however, mortality probabilities increased with local stand basal area, probably due to higher fuels and local fire intensity. At the median basal area (37 ft^2/acre), fires killed mostly small trees (dbh < 2 inches). In more dense stands, fires also killed larger trees (dbh up to 5-6 inches). Mortality rates varied little among species except for larger trees in patches with high basal area, where survival rates were higher for ponderosa pines than for Douglas-firs and other conifer species. Overall, prescribed fires were effective for thinning stands from below, raising canopy base heights, and, to some extent, favoring ponderosa pine over Douglas-fir and lodgepole pine. Additional fires (and possibly some mechanical thinning) may be needed, however, to maintain low surface fuel loads, further modify canopy fuels, and further increase forest resilience to future wildfires.

Introduction

Modifying wildfire severity through manipulation of forest structure and surface fuels has become an important management objective in many dry coniferous forest types of North America (Graham et al. 2004, Peterson et al. 2005). Decades of fire exclusion have significantly altered forest stand density and species composition, particularly in dry western forests dominated by ponderosa pine (*Pinus ponderosa*) and Douglas-fir (*Pseudotsuga menziesii*) that historically supported fire regimes with

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short mean fire return intervals and mostly low severity fires (Cooper 1960, Covington and Moore 1994). These changes in forest structure and surface fuels increase risks for extreme fire behavior and large, stand-replacing wildfires in areas that formerly supported low- and mixed-severity fire regimes (Covington and Moore 1994, Graham et al. 2004).

Efforts to restore fire resiliency (the ability of forests to tolerate fire and recover quickly following wildfire) in dry coniferous forests have focused on reducing surface fire intensity and severity, reducing the probability of crown fire initiation, reducing the extent of crown fire spread, and creating defensible spaces for fire suppression activities (Agee 1996, Peterson et al. 2005). Mechanical thinning and prescribed fire are the tools commonly proposed for achieving these objectives. Mechanical thinning (with subsequent treatment of residual coarse woody debris) is typically recommended for altering stand structure and species composition, while prescribed fire is often recommended for reducing and maintaining acceptable levels of surface fuels (Graham et al. 2004, Peterson et al. 2005).

Young, regenerated forests present a challenge for increasing fire resilience through fuel reduction treatments. Opportunities for modifying stand structure with mechanical thinning in these young forests may be limited due to high unit treatment costs for thinning and pruning, large numbers of acres needing treatment, lack of merchantable timber to help offset treatment costs, reduced management emphasis on timber production, and limited funds for timber stand improvement activities. However, increasing fire resilience in young ponderosa pine and dry Douglas-fir forests is important because such forests (1) are abundant, (2) often have stand structural characteristics that support crown fire behavior, and (3) are likely to experience wildfire prior to reaching maturity.

In this paper, we present early results from an ongoing study of prescribed fire effects on fuels and stand structure in young, dry, ponderosa pine and Douglas-fir forests regenerated after stand-replacing wildfire in 1970. We wanted to know whether spring prescribed burning could be used effectively to increase the fire resiliency of these forests while perhaps also achieving other management objectives, such as thinning stands and increasing structural heterogeneity, and reducing risks of large-scale insect disturbances. Specific goals for increasing fire resiliency in mature forests typically include: (1) reducing surface fuels, (2) increasing live crown base heights, (3) reducing canopy bulk densities, and (4) retaining large trees of fire resistant species (Graham et al. 1999, Agee and Skinner 2005, Peterson et al. 2005). We use the first three of these goals as benchmarks for evaluating prescribed fire treatment efficacy. However, large trees of fire-resistant species are typically scarce or nonexistent following stand-replacing wildfires, so we propose an alternative goal of promoting the rapid development of large, fire-resistant trees as our fourth benchmark. Although in this paper we evaluate treatment efficacy primarily with respect to fire resiliency objectives, we note that promoting rapid development of large trees is also consistent with forest health and productivity objectives.

Methods and Materials

Study Area

The study area was the Preston Creek drainage within the Entiat River Basin, approximately 32 miles north of the town of Wenatchee in north-central Washington

State. Soils are well-drained sandy loams and loamy sands, derived primarily from volcanic ash and pumice deposits that overlay granitic bedrock. The climate features cold, moderately wet winters and warm, dry summers. Annual precipitation is about 23 inches per year (1961-1970), about 70% of which falls as snow (Helvey et al. 1976). The drainage supports a variety of dry forest types dominated by ponderosa pine, Douglas-fir, and lodgepole pine (*Pinus contorta*).

Fire scar records from the lower Entiat River Basin indicate that pre-settlement fire regimes (before 1860) featured fires of generally low severity with mean fire return intervals of about seven years (Everett et al. 2000). Fire frequencies became more spatially variable during the settlement period (1860-1910), but mean fire return intervals increased only slightly to 7-10 years. However, mean fire return intervals increased substantially (to about 40 years) during a subsequent period of active fire suppression beginning around 1910 (Everett et al. 2000).

Since 1970, large, stand-replacing fires have burned large portions of the Basin. The 1970 Entiat Fire burned 61,000 acres within the Basin. The Dinkleman and Tyee fires burned a combined 146,000 additional acres in 1988 and 1994, respectively. Reforestation efforts have produced extensive areas of young, even-aged forests (up to 34 years old) with relatively uniform structure, spatial pattern, and species composition. Post-fire logging and subsequent fuel treatments removed much of the coarse woody debris, so current surface fuels consist primarily of decaying stumps and fine fuels produced by the existing vegetation.

Prescribed Fire Treatment

As part of an overall management strategy for the Entiat Basin, managers have developed the following objectives for these young, regenerated forests: (1) reduce short-term (0-30 years) risks of severe disturbance from fire and insects, (2) take advantage of the current thinning window and attempt to expand it, (3) put the landscape and component stands on a trajectory toward conditions closer to the natural range of variability, and (4) restore fire as an active ecosystem process. To help them achieve these objectives, Entiat Ranger District staff proposed using prescribed fire. The primary benefits of the prescribed fire treatments were expected to be reduced risks of severe wildfire, reduced stand densities (thinning from below) and reintroduction of fire as an ecosystem process.

For this study, prescribed fires were ignited on six contiguous prescribed fire management units totaling 256 acres on four different days between March 23 and April 7, 2004 (*fig. 1*). Fires were ignited using the strip head-fire method. Residual snowpack protected adjacent north-facing slopes and higher elevation stands against fire escape and spotting.

Data Collection and Analysis

A randomized grid sampling approach was used to assess treatment effectiveness for modifying forest stand structure, species composition, and live fuels. Field surveys occurred in late August and September, 2004, at the end of the first growing season following fire. Sample plots were established on a square grid pattern at a density of one sample plot per acre, for a total of 264 sample plots. Plot centers were staked to allow repeated sampling. Variability of fire activity within units was assessed by recording the percent soil surface area burned for each plot.

At each sample plot, prescribed fire effects on forest stand structure were assessed by measuring fire effects on individual trees within a 14-foot radius of the

Figure 1. Management units in Preston Creek drainage burned with prescribed fire between March 23 and April 7, 2004. Photo was taken in late April, 2004.

plot center (616 ft^2 area). Species, diameter at breast height (dbh), height, crown class, and post-fire status (alive or dead) were recorded for each tree deemed to have been living before the fire. Pre-fire and post-fire height to the base of the live crown were also recorded for each tree, with pre-fire crown condition reconstructed based on the presence of scorched needles that were judged to have been alive prior to the fire. This retrospective approach was feasible because of the generally low intensity and severity of the prescribed fires.

Tree density, stand basal area, canopy bulk density, and canopy base height were calculated for each plot before and after fire based on pre-fire and post-fire plot tree lists (living trees only). Canopy bulk densities and base heights were calculated using the CrownMass software (FMAPlus 2003). For plots without trees, tree density, stand basal area, and canopy bulk density were set to zero, while canopy base height was undefined and treated as a missing value.

Fire effects on stand structure and canopy fuels were analyzed using a "before-after" repeated measures design using linear mixed models (Littell et al. 2006). Measurement plots were treated as random factors nested within prescribed fire management units (the latter being the replicated experimental units). Tree mortality was modeled using a similar, but nonlinear, mixed model (logistic regression) with plot-level random effects. The type I error rate for judging statistical significance of treatment effects was set at 10% ($\alpha = 0.10$) for all analyses.

Results

Most of the sample plots were on 20-60% slopes and southerly to southeasterly aspects. Of the 264 sample plots, 45 (17%) contained no trees (individuals taller than 4.5 feet dbh) prior to treatment. The number of plots without trees increased to 67 (+25%) after the prescribed fire treatments. Ponderosa pine was the most abundant tree species across all size classes, but Douglas-fir was also common, particularly in the smallest size classes. Lodgepole pine was present on many plots, but was usually a minor species component of the stand.

The prescribed fire treatments significantly changed stand structural attributes, including mean tree density and stand basal area. Fires reduced mean tree density from 426 to 280 trees per acre (SE = 23 trees/acre) and reduced mean stand basal area from 47 to 38 ft^2/acre (SE = 4.9 ft^2/acre). *Figures 2a, 2b* show that the prescribed fires shifted the frequency distributions of plot-level tree density and basal area estimates toward lower local density and basal area.

Prescribed fires also modified forest canopy fuels by raising canopy base heights and reducing canopy bulk densities. For plots with at least one tree, prescribed fires raised canopy base heights by 5.3 ± 0.4 feet (mean ± SE), from 1.0 to 6.3 feet and increased variability in canopy base heights among plots (*fig. 2c*). The treatments also reduced canopy bulk density somewhat, from 0.0064 to 0.0061 lbs/ft^3 (SE = 0.0004 lbs/ft^3).

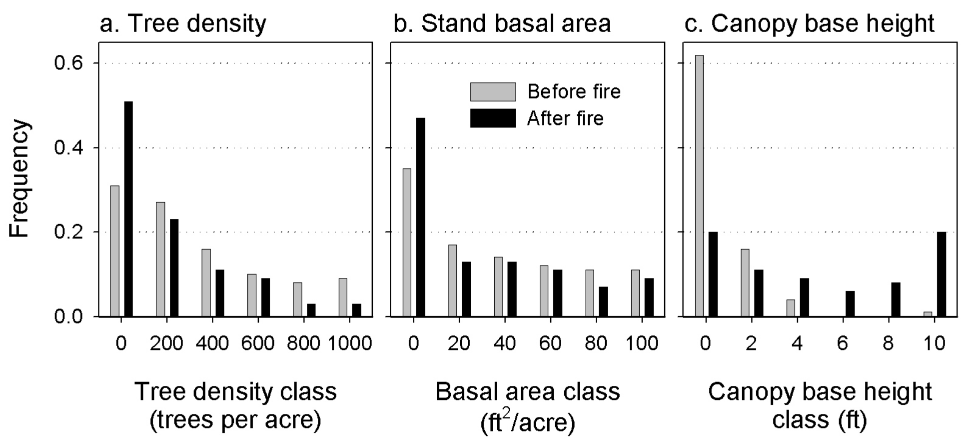

Figure 2—Changes in frequency distributions for tree density, stand basal area, and canopy base height estimates for all plots in the prescribed fire management units. Plots were grouped into classes for presentation purposes, and the horizontal axis tick labels indicate the lower bound for each class. Gray bars show pre-fire frequencies and black bars show post-fire frequencies.

Fire behavior and corresponding fire treatment effects were spatially variable within the prescribed fire management units. Field assessments of percent forest floor charred showed that 45% were completely burned (100% forest floor charred), 27% were partially burned (5-95% charred), and 28% remained unburned (0% charred). Observing that a disproportionately high percentage of plots without trees remained unburned, we tested for and found a significant positive correlation between plot basal area (a proposed surrogate for local productivity and fuels) and percent forest floor charred. This suggested that plot basal area might explain some variance in fire behavior and effects among plots.

Tree mortality/survival responses to prescribed fire varied with tree size and species. Probability of tree death from fire declined with increasing tree diameter for all species. Ponderosa pines had higher expected mortality rates than Douglas-fir and lodgepole pine (the latter two species were analyzed as a group) for trees with dbh less than one inch. However, tree mortality rates also varied significantly with plot basal area. On plots with median basal area, predicted mortality rates were very low (< 10%) for trees over two inches diameter (*fig. 3*). On plots with high basal area

(90th percentile and higher), mortality rates were over 10% for ponderosa pines with dbh less than 3.5 inches and other conifers with dbh less than 5 inches (*fig. 3*).

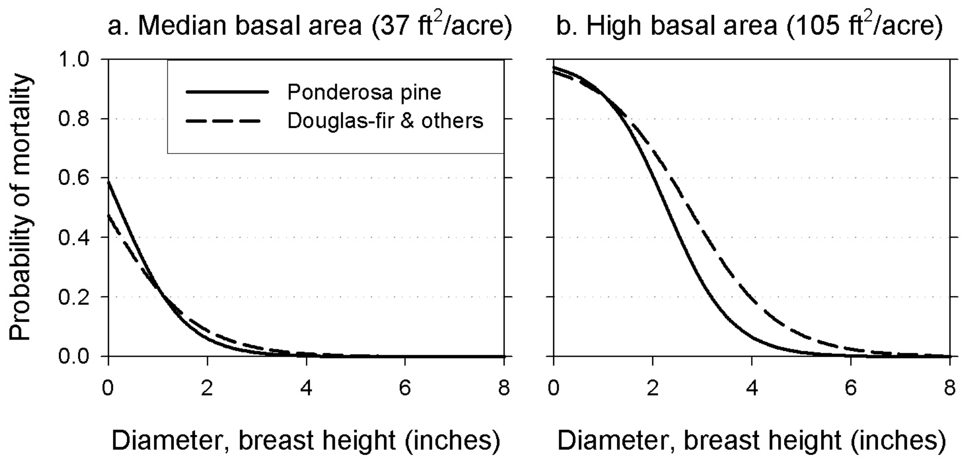

Figure 3—Predicted tree mortality probabilities for ponderosa pine and other conifers as influenced by tree diameter (dbh). Predicted mortality also varies with pre-fire plot basal area, as seen by differences between predicted mortality functions for a) the 50th percentile (median) basal area, and b) the 90th percentile (high) basal area.

Because the fires killed mostly smaller trees, the fire treatments changed tree size distributions. Before prescribed fire, the diameter distribution of trees across all management units was bimodal, with peaks in the sapling (0-2 inch) and small tree (4-6 inch) dbh size classes (*fig. 4*). High mortality rates within the sapling size class produced a post-fire tree size distribution with a single mode in the small tree size class (*fig. 4*). However, sapling densities were still relatively high overall due to their continued abundance on unburned plots within the management units. Omitting unburned plots from the analysis produced the expected unimodal tree size distribution with the highest mean density in the small tree class (*fig. 4*).

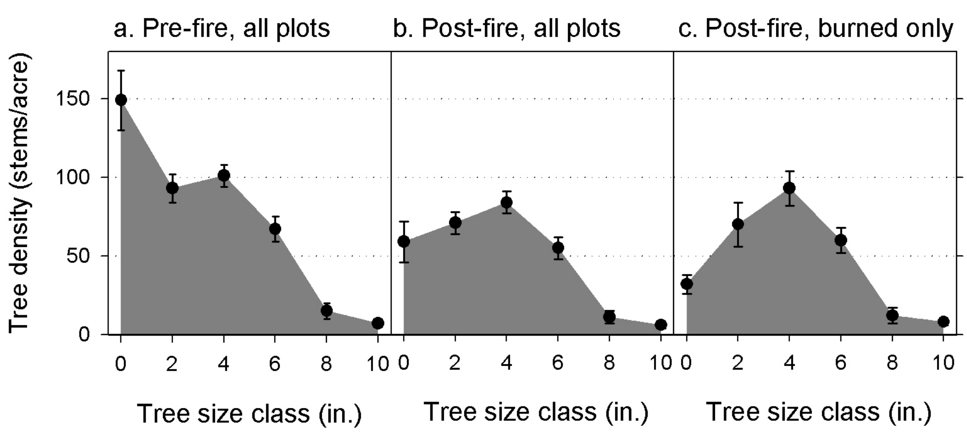

Figure 4—Mean tree size distributions on management units for a) all plots before prescribed fire, b) all plots after prescribed fire, c) all burned plots (minimum 5% of forest floor charred by fire) after prescribed fire.

Discussion

We proposed four treatment goals for assessing the efficacy of prescribed fire for modifying fuels and increasing fire resilience in young coniferous forests: reduce surface fuels, increase height to live crown base, reduce canopy bulk density, and promote development of large trees of fire-resistant species. Based on these goals, spring prescribed fire proved reasonably effective.

Visual inspection of post-fire surface fuels suggested that spring prescribed fires consumed most of the fine surface fuels and most of the decaying stumps from post-fire salvage logging in the completely burned areas. In the short term, surface fuels may not be sufficient to support even surface fires. However, the fires also produced future fine fuels by scorching tree crowns, killing small trees, and topkilling shrubs. As scorched needles and dead branches accumulate on the forest floor, fire risks will increase again and subsequent prescribed fire treatments may be needed to maintain low surface fuel loads and limit potential surface fire intensity.

The fires were also effective at reducing vertical continuity of fuels. By killing most understory tree seedlings and saplings and raising the height to the base of the live crown for surviving trees, the fires significantly reduced ladder fuels, increased canopy base height, and reduced risks of torching. Based on the nomograms provided by Scott and Reinhardt (2001), the prescribed fires increased the torching index by an average of about 15 km/hr for normal summer drought conditions with a surface fuel model 5 (brush, 2 feet) and 100% foliar moisture content. By monitoring surface fuel accumulations, subsequent prescribed fires can be planned to further raise canopy base heights and prevent development of new ladder fuels.

The fires did little to reduced risks of active crown fire, as mean canopy bulk density was reduced by only about 5%. The nomograms provided by Scott and Reinhardt (2001) suggest that such a small change in canopy bulk density would have little effect on the crowning index for the stand overall. However, canopy bulk density and fire effects were both spatially variable within the management units, so one would expect crowning behavior to vary as well. Based on fire behavior during large wildfires in central Washington State in 1994, Agee (1996) established a threshold value of 0.100 kg/m^3 (0.00615 lbs/ft^3) for canopy bulk density in ponderosa pine and Douglas-fir forests, above which crown fire behavior was likely under wildfire condition and below which no crown fire activity occurred. Our mean canopy bulk densities were very close to this threshold both before and after the fires. Future treatments will likely be required to more significantly reduce crowning index and achieve management objectives for increasing forest resiliency to wildfire.

Finally, the prescribed fires promoted the development and dominance of larger trees of fire resistant species. Larger trees had much higher survival rates than smaller. Our analysis also indicated that ponderosa pine trees had lower mortality rates than other conifers for trees with diameters greater than two inches. Once trees recover from reductions in crown volume, we expect that the lower stand densities will enhance growth rates of surviving trees by reducing competition for soil water and other limiting resources. These changes may also serve to reduce risks of large-scale insect damage.

Overall, spring prescribed fire treatments proved to be modestly effective for modifying fuels and increasing fire resilience in these young ponderosa pine forests. Additional prescribed fires will be needed in the next decade to further improve fire resilience and maintain low surface fuel loads. Because costs of treating stands with prescribed fire are considerably less than with mechanical thinning and pruning, multiple fires may be easily justified economically. We also expect fire prescriptions will become broader over time as fire resilience improves, making future fire treatments easier.

References

Agee, J. K. 1996. **The influence of forest structure on fire behavior.** In: Proceedings of the 17th Annual Forest Vegetation Management Conference; 1996 January 16-18; Redding, CA. Pages 51-68.

Agee, J. K.; Skinner, Carl. N. 2005. **Basic principles of forest fuel reduction treatments.** Forest Ecology and Management 211:83-96.

Cooper, C. F. 1960. **Changes in vegetation, structure, and growth of southwestern pine forests since white settlement**. Ecological Monographs 30: 129-164.

Covington, W. W.; Moore, M. M. 1994. **Southwestern ponderosa pine forest structure: changes since Euro-American settlement.** Journal of Forestry 92: 39-47.

Everett, R. L.; Schellhaas, R.; Keenum, D.; Spurbeck, D.; Ohlson, P. 2000. **Fire history in the ponderosa pine/Douglas-fir forests on the east slope of the Washington Cascades.** Forest Ecology and Management 129: 207-225.

FMAPlus [computer software]. 2003. Estacada, OR: Fire Program Associates/Acacia Services; http://www.fireps.com.

Graham, R. T.; Harvey, A. E.; Jain, T. B.; Tonn, J. R. 1999. **The effects of thinning and similar stand treatments on fire behavior in western forests.** Gen. Tech. Rep. PNW-GTR-463. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station; 27 p.

Graham, R. T.; McCaffrey, S.; Jain, T. B. 2004. **Science basis for changing forest structure to modify wildfire behavior and severity.** Gen. Tech Rep. RMRS-GTR-120. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station; 43 p.

Helvey, J. D.; Fowler, W. B.; Klock, G. O.; Tiedemann, A. R. 1976. **Climate and hydrology of the Entiat Experimental Forest watersheds under virgin forest cover.** Gen. Tech. Rep. PNW-GTR-042. Portland, OR: Pacific Northwest Research Station, Forest Service, U.S. Department of Agriculture; 18 p.

Littell, R. C.; Milliken, G. A.; Stroup, W. W.; Wolfinger, R. D.; Schabenberger, O. 2006. SAS for mixed models. Second Edition. Cary, NC: SAS Institute, Inc. 814 p.

Peterson, D. L.; Johnson, M. C.; Agee, J. K.; Jain, T. B., McKenzie, D.; Reinhardt, E. D. 2005. **Forest structure and fire hazard in dry forests of the western United States.** Gen. Tech. Rep. PNW-DTR-628. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station; 30 p.

Scott, J. H.; Reinhardt, E. D. 2001. **Assessing crown fire potential by linking models of surface and crown fire behavior.** Res. Pap. RMRS-RP-29. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 59 p.