FIELD NOTE

Impact of Spring or Fall Repeated Prescribed Fire on Growth of Ponderosa Pine in Eastern Oregon, USA

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ABSTRACT

Prescribed burning is used to reduce fuel loads and to return fire to its historic disturbance role in western forests. Managers need to know the effects of prescribed fire on tree growth. Growth of residual ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.) was measured in an existing long-term study of the effects of season-of-prescribed burn in combination with a single or a repeated burn. Each of six previously thinned mixed-age stands in the Blue Mountains near Burns, Oregon, was subdivided into three experimental units, and one of three treatments was randomly assigned to each: fall 1997 burn, spring 1998 burn, and no burn (control). Treatments were operational-sized prescribed burns. In 2002/2003 each burned unit was split, and one-half was burned again, maintaining the original season of burn. Sample trees were evaluated for growth 5 and 10 seasons after the initial prescribed fires. We conclude that after accounting for the crown scorch proportion neither a single spring or fall prescribed fire treatment nor a repeated fire treatment 5 years later affected the growth of thinned ponderosa pine 10 years after the initial 1997/1998 fires. A linear regression is included to estimate bark thickness based on dbh.

Keywords: bark thickness, Blue Mountains, *Pinus ponderosa*

Fire is an important consideration in understanding the ecology and management of ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.) (Barrett 1979, Agee 1993, Vance et al. 2001). As a result of decades of fire exclusion and suppression, timber harvesting, and overgrazing, many ponderosa pine stands are currently past their historic fire return interval, resulting in heavy fuel accumulations, which put stands at risk for uncharacteristically severe wildfires (Weaver 1943, Covington and Moore 1994, Kolb et al. 1994). Prescribed burning with or without mechanical thinning is widely used as a tool to reduce stand densities and fuel loads and restore fire to its historic disturbance role in western interior forests (Weaver 1943, Agee 1993, Covington and Moore 1994). A single prescribed burn is often insufficient to meet management goals of reducing fuel loads and stocking levels. To mimic the historic role of fire, periodic reburns will be necessary and should be a focus of current and future research (Agee 1996). Managers of western interior forests generally have two windows of opportunity for prescribed burning: late spring and fall. The impact of both season of prescribed fire and repeated prescribed fire on growth of ponderosa pine trees is poorly understood and could be an important consideration in decisions regarding burn timing and frequency. Previous studies of pine growth reported various conclusions regarding the impact of growth after prescribed fire including increases (Van Sickle and Hickman 1959, Wyant et al. 1983), decreases (Landsberg et al. 1984, Grier 1989, Busse et al. 2000), and minimum change (Sutherland et al. 1991, Sala et al. 2005, Zausen et al. 2005). The objective of this field note is to report the 10-year experimental results of a replicated study on the effects of single or repeated spring or fall prescribed burn treatments on the height, diameter, and basal area growth of ponderosa pine trees in the Blue Mountains of Oregon.

Background

In 1996, a study (Thies et al. 2005) was initiated to examine the influence of season of burn (SOB; spring versus fall) on the appearance of black stain root disease (BSRD) in ponderosa pine trees after prescribed fire. It was hypothesized that the insect vectors of BSRD were influenced by the season of prescribed burning and thus appearance of and mortality caused by BSRD. The study was established in six stands of mixed-age ponderosa pine with scattered western juniper (*Juniperus occidentalis* Hook.) and mountain mahogany (*Cercocarpus ledifolius* Nutt.) in the south end of the Blue Mountains (Emigrant Creek Ranger District, Malheur National Forest) near Burns, Oregon, USA. Elevations range from 1,570 to 1,740 m. Soils are moderately to well drained gravelly and clay

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This article uses metric units; the applicable conversion factors are: centimeters (cm): 1 cm = 0.39 in.; meters (m): 1 m = 3.3 ft; square meters (m^2): 1 m^2 = 10.8 ft^2; hectares (ha): 1 ha = 2.47 ac.

Table 1. Summary table showing ranges for weather and fire conditions of prescribed burns.

Burn date	Temperature (° C)	Relative humidity (%)	Wind speed (km hr^{-1})	Flame length (cm)	10-hr fuel moisture (%)
Fall 1997	14–21	24–40	0–6	30–150	No data
Spring 1998	16–22	24–44	0–8	60–150	No data
Fall 2002	11–18	17–41	0–11	30–90	10–14
Spring 2003	21–23	30–32	0–10	30–60	11–14

Table 2. Summary table showing 1998 postfire means by treatment for diameter, height, basal area, trees per ha, plot area burned, mean crown scorch proportion, and bole scorch proportion.

	dbh (cm)	Height (m)	Basal area (m^2 ha^{-1})	Trees ha^{-1}	Area burned (%)	Crown scorch (proportion)	Bole scorch (proportion)
Control (n = 305)	28.8 (9.1–94.0)	14.2 (4.0–33.8)	17.89	224	NA	NA	NA
Fall burn (n = 243)	28.2 (8.9–76.7)	14.1 (4.0–35.3)	18.79	178	59.2 (10–100)	0.22 (0.0–1.0)	0.14 (0.0–0.54)
Spring burn (n = 304)	30.4 (8.4–101.6)	15.0 (3.9–38.9)	17.67	218	56.7 (10–100)	0.16 (0.0–1.0)	0.08 (0.0–0.42)
Burn once (n = 430)	29.1 (8.4–101.6)	14.5 (3.9–38.9)	18.01	215	42.1 (0–100)	0.21 (0.0–1.0)	0.11 (0.0–0.51)
Burn twice (n = 422)	29.3 (8.6–81.5)	14.5 (4.0–33.0)	17.89	199	36.8 (0–100)	0.16 (0.0–1.0)	0.10 (0.0–0.54)

Where appropriate, variable ranges are shown in parentheses. NA, not applicable.

loams derived from basalt, andesite, rhyolite, and tuffaceous interflow materials. Climate is characterized by short growing seasons with annual rainfall averaging 43 cm. Location, elevation, aspect, slope, and plant communities are given in Thies et al. (2005; Table 1), and details on understory vegetation are available in Kerns et al. (2006).

Trees were generally between 80 and 100 years old with intermittent individuals of approximately 200 years (unpublished data on file at the Emigrant Creek Ranger District). The prefire range of means for stand descriptors for the six stands are as follows: dbh, from 25.0 to 30.8 cm; tree height, from 12.2 to 16.3 m; trees ha^{-1}, from 203 to 328; and basal area (outside bark), from 17.2 to 19.4 m^2 ha^{-1}. Each stand was thinned in 1994 or 1995, and burns were prescribed to reduce naturally accumulated fuels and slash, reduce stocking of saplings and poles, stimulate low levels of natural regeneration, create snags, reinvigorate shrubs and herbaceous plants, and reintroduce fire into ecosystems having a history of frequent low-intensity fire.

Each of the six stands was designated a replicate and divided into three contiguous experimental units similar in type, aspect, and slope. Experimental units (n = 18) had a mean size of 13.2 ha. Three treatments, no-burn, fall burn, and spring burn, were randomly assigned to experimental units within each replicate. Burn treatments were applied during mid-October of 1997 (fall burn) or mid-June of 1998 (spring burn). All spring burn treatments occurred just after snowmelt and before significant growth occurred. Hand-carried drip torches were used to ignite all fires. The ignition pattern in all cases was multiple-strip head fires spaced with a goal to maintain an average 60-cm flame length. Conditions for the prescribed fires are summarized in Table 1. All treatments were conducted within the burn prescription and were representative of operational burns, given weather and fuel conditions. Fuels included slash from the thinning conducted in 1994 or 1995, naturally cast pine needles, and naturally sloughed branch wood.

Immediately after the spring 1998 burn treatments, six 0.2-ha circular sampling plots were established at least 100 m apart and approximately 100 m within each experimental unit in locations representative of the average stand and burn conditions of that unit. Of the 190 ha total in the experimental units, a small percentage of the area had few ponderosa pine trees and was avoided for plot placement; rock outcroppings (1%), thickets of mountain-mahogany (1%), areas of no fire or treeless openings (10%), or high fire severity where most trees were killed (2%). Relative fire severity on experimental units can be compared based on the area burned on plots and the proportion of crown and bole scorch of the ponderosa pine trees. Key 1998 postfire treatment summary information is presented in Table 2 for tree diameter, height, basal area, residual live trees per ha, plot area burned, crown scorch, and bole scorch. Total tree heights and damage heights were measured to the nearest 3.0 cm with a laser hypsometer. Two individuals independently estimated the percentage of surface area burned on each plot to the nearest 5%, and a consensus percentage was recorded. Crown scorch proportion was calculated as the length of the scorched (scorched or consumed needles) portion of a crown as a proportion of the total crown. Bole scorch proportion was calculated as the maximum bole scorch (blackened) height as a proportion of total tree height.

The original objective of the SOB study was to determine the interaction of disease, insects, and fire on survival of ponderosa pine trees. On each plot, all standing conifers (excepting junipers) greater than 7.5 cm dbh were tagged and evaluated (noninvasively) for tree morphology and fire damage variables. Further details of stand structure, variables measured, and burn treatments are available in Thies et al. (2005, 2006). Ponderosa pine trees alive at the time of the burns (n = 5321) were monitored each fall for status (live/dead) (Thies et al. 2005, 2006).

In fall 2002, objectives for the SOB study were expanded to include an interval-of-burn component to examine the effect of repeated prescribed burning treatments at 5-year intervals. Each of the 18 experimental units was divided roughly in half so as to include three of the original six sample plots; one half was randomly selected and designated to be reburned (5 years after the first burn treatment), and the other half received only the initial burn. The control units were similarly split and randomly designated as part of the one burn and multiple burn treatments even though no burning treatment was applied. This was done to ensure that all analyses remained balanced. The experimental units designated for reburn were burned in fall 2002/spring 2003, maintaining the same season of burn and burn prescription as for the original study (Thies et al. 2005). Each fall when plots were examined, all 18 experimental units had developed without further disturbance for the same number of growing seasons (Thies et al. 2005).

Table 3. Means, 95% CIs, and *P* values for both differences in number of times burned and season of burn × burn interval interaction, for diameter change, height change, and three RBAI.

Variable	Burned twice (95% CI)	Burned once (95% CI)	*P* for burn interval difference (*df*)	*P* for treat × burn interval differences (*df*)
Diameter change 1998–2007 (cm)	2.86 (2.59–3.13)	2.87 (2.60–3.14)	0.9525 (1/15)	0.1080 (2/15)
Height change 1998–2007 (m)	1.81 (1.57–2.06)	1.74 (1.50–1.99)	0.5583 (1/15)	0.7827 (2/15)
RBAI-5	1.62 (1.49–1.75)	1.62 (1.49–1.75	0.9575 (1/15)	0.7993 (2/15)
RBAI-10	1.79 (1.58–1.99)	1.75 (1.54–1.96)	0.7614 (1/15)	0.7692 (2/15)
RBAI-55	1.16 (1.02–1.31)	1.13 (1.00–1.29)	0.5271 (1/15)	0.9980 (2/15)

Determination of tree growth response was not included in the original objectives of the season of burn study; however, the design and availability of this ongoing study lent itself to expanded objectives. We report here the effects of a single or repeated spring or fall prescribed burning treatment on growth of surviving ponderosa pine trees 10 years after the initial prescribed burning treatments.

Methods and Materials

During establishment of the SOB study in the fall of 1998, numbered aluminum tags were nailed to all plot trees on the uphill side at standard breast height, 1.37 m above mineral soil. Dbh was measured immediately above the nail with a diameter tape and recorded to the nearest 0.25 cm. Tree heights were measured to the nearest 3.0 cm with a laser hypsometer. In the unburned treatment units of each stand, bark thickness at breast height was measured in two places, one on the uphill side and one 90° clockwise, on every tree with a tag number ending with 0 or 5. These bark measurements were used to create a separate linear regression equation for each of the six replicate stands, for estimating bark thickness based on dbh. In the fall of 2007, a subsample of ponderosa pine trees on each treatment unit, those with a tag number ending with 0 or 5 ($n = 852$), was remeasured for height and diameter, and two increment cores were taken at breast height, one on the uphill side and one 90° clockwise. Radial growth was measured in the field to the nearest 0.06 cm (0.025 in.) using a ruler and, when necessary, a 16× hand lens. Radial growth for periods of 5 and 10 years postfire and 10 years prefire was recorded for both cores, and the mean growth increment was calculated. The 2007 dbh, mean radial growth increment, and mean bark thickness from the 1998 regression equations were used to calculate the annual basal area increment (BAI; inside the bark) for each growth period. Tree growth is often more influenced by pretreatment growth rate than by experimental treatments, making it common to use each tree as its own control (Salonius et al. 1982, Peterson et al. 1991, Skov et al. 2005). To accomplish this, we divided the postfire BAI by the prefire BAI to create a relative basal area index (RBAI). This RBAI has no units, is equal to 1.0 if the growth rate remained constant, is more than 1.0 if growth had increased, and is less than 1.0 if growth had decreased. Three RBAIs were created for comparison: RBAI-5, 5 years postfire/10 years prefire; RBAI-10, 10 years postfire/10 years prefire; and RBAI-55, second 5 years postfire/first 5 years postfire. The use of the "relative basal area increment" normalizes the growth increment to help account for differences in tree position, diameter, vigor, and stocking levels, making it more likely to detect an actual difference due to the experimental treatments (Reinhardt and Ryan 1988).

The experimental unit means for all response variables were tested for treatment differences using a mixed-effects analysis of covariance with a randomized complete block split-plot design with 6 blocks (stands), three season-of-burn treatments (fall burn, spring burn, and control), and a burn interval split plot with two levels (one burn or two burns at 5-year intervals). The experimental unit mean for crown scorch proportion from the initial 1997/1998 prescribed burns was used as a covariate to help account for fire severity to better assess both season and repeated burning growth differences. Two-way interactions between the covariate and season or interval treatments as well as the three-way interaction were checked for significance. During analysis, model assumptions of normality and equal variance were tested using normal probability plots and plots of residuals (observed versus predicted), respectively. When necessary, transformations to correct for these assumptions are noted. Treatment differences were considered significant at $\alpha = 0.05$, and where differences exist, *P* values and confidence intervals (CIs) were adjusted for multiple comparisons using the Tukey honest significant difference method (Ramsey and Schafer 1997).

We are unaware of a published bark thickness regression based on dbh for our study area. To make this relationship available for future studies, the bark thickness measurements used to calculate the inside of the bark basal areas were combined from all six stands, and a statistically significant ($P < 0.05$) general regression equation for estimating breast height bark thickness based on dbh was developed. All analysis was done using SAS 9.2 (SAS Institute, Inc., 2002–2008).

Results

Means, 95% CIs, and analysis results for burn interval and burn interval × burn season interaction are presented in Table 3 and for burn season in Table 4. There were no significant differences for burn season or for the burn season by burn interval interaction. There were no differences by burn treatment for diameter change, height change, RBAI-5, or RBAI-10. There was a significant difference by burn season for RBAI-55 ($F_{2, 10} = 5.60$, $P = 0.023$); the fall treatment RBAI-55 is 1.12 times that of the control (Tukey's adjusted $P = 0.028$, adjusted 95% CI 1.00–1.21). A natural logarithm transformation of the response variable (RBAI-55) was done to meet model assumptions of normality and equal variance.

None of the interactions between treatments and the crown scorch proportion covariate were significant ($P > 0.05$). For both the RBAI-5 and the RBAI-10 responses, the crown scorch proportion covariate was significant. For each 1.0% increase in the proportion of crown scorch, the RBAI-5 will decrease by 0.013 ($F_{1, 14} = 12.86$, $P = 0.003$, 95% CI 0.00 to -0.026). For each 1.0% increase in the proportion of crown scorch, the RBAI-10 will decrease by 0.022 ($F_{1, 14} = 10.96$, $P = -0.005$, 95% CI -0.009 to -0.035).

The following model describes the assumed relation between bark thickness and dbh:

$$\ln(\text{bt}_i) = \beta_0 + \beta_1 \ln(\text{dbh}_i) \quad (1)$$

Table 4. Means, 95% CIs, and *P* values for treatment differences in season of burn, and changes in diameter, height, and RBAI.

Variable	Control (95% CI)	Fall (95% CI)	Spring (95% CI)	*P* for treat differences (*df*)
Diameter change 1998–2007 (cm)	2.95 (2.60–3.30)	2.97 (2.61–3.32)	2.67 (2.31–3.02)	0.2992 (2/10)
Height change 1998–2007 (m)	1.82 (1.50–2.14)	1.66 (1.34–1.98)	1.85 (1.53–2.17)	0.5214 (2/10)
RBAI-5	1.71 (1.54–1.87)	1.57 (1.40–1.73)	1.59 (1.42–1.75)	0.3825 (2/10)
RBAI-10	1.86 (1.55–2.16)	1.76 (1.46–2.07)	1.68 (1.38–1.99)	0.6736 (2/10)
RBAI-55	1.07a (0.93–1.23)	1.19b (1.04–1.37)	1.17ab (1.02–1.35)	0.0234 (2/10)

Row means with the same letter are not significantly different at $P = 0.05$.

where ln is the natural logarithm, bt_i is the mean breast high bark thickness in centimeters of the *i*th tree, and dbh_i is the dbh in centimeters of the *i*th tree. The coefficients β_0 and β_1 are the intercept and slope, respectively. Application of ordinary least squares regression to the data from 325 trees ranging in dbh from 8.9 to 94.0 cm yielded the following estimator of bark thickness:

$$\ln(\mathrm{bt}) = -1.687 + 0.746\ \ln(\mathrm{dbh}) \qquad (2)$$
$$(0.062)\ (0.019)$$

The numbers in parentheses below the regression equation are SEs of the coefficients. The coefficient of determination (R^2) is 0.829. Caution should be exercised when this regression is used outside of the geographical area for which it was developed.

Discussion

Our results show that after accounting for the crown scorch proportion sustained in the initial prescribed burns, neither burning season nor repeat burning significantly affected the change in ponderosa pine tree height, diameter, RBAI-5, or RBAI-10. The RBAI-5 and RBAI-10 for all treatments are greater than 1.0 (Tables 3 and 4), indicating that the growth rates increased for the 5 or 10 seasons posttreatment relative to the 10 seasons pretreatment. We speculate that this is a result of the thinning in all stands 3 years before treatment. The total growth response to thinning was a combination of the response to pretreatment mechanical thinning and to the thinning resulting from the fire treatments.

Fire damage and tree mortality were highest in the initial burns and in the fall treatments. Few trees died as a result of subsequent burns, adding little thinning effect due to postfire mortality; this lack of thinning is consistent with the lack of a significant growth response.

The RBAI-55 was significantly greater in the fall burn units than in the controls. This finding indicates that the growth rate of the trees in the fall treatment had increased during the second 5-year postfire period relative to the first 5 years postfire. In general, our fall burns had higher fire severity and caused more tree mortality than the spring burns (Thies et al. 2005). The increase in growth rate seen here in the more severe fall fires could be a result of reduced competition from the additional thinning effect. The delayed response to burning is similar to the delayed growth response that most tree species exhibit after thinning. If this trend continues, height and diameter growth differences between treatments could become significant in the future. Although both spring and fall prescribed fire treatments were within prescription, the fall fire treatments probably burned hotter than the spring fire treatments. In Table 2, the residual trees per ha are less in the fall fire treatments and the mean crown scorch and bole scorch are greater in the fall fire treatments than in the spring fire treatments. This result indicates that there are fewer trees competing for resources, and those residual trees received more heat damage than the trees in the spring fire treatment. We speculate that the lag in response may be accounted for both because of the natural lag after a thinning and because the residual trees had to replace crown and recover from heat damage, but having done so the residual trees in the fall burn are in a better position to capture more resources and add increased basal area.

The prescribed burns did not result in significant changes in means for dbh, tree height, trees per ha, or basal area (Thies et al. 2005). This finding is consistent with observations in ponderosa pine forests in northern Arizona by Zausen et al. (2005), who reported that the effects of fire on tree growth were negligible or indistinguishable from effects of thinning. Sutherland et al. (1991), also working in northern Arizona, reported an initial decrease in ponderosa pine tree growth for 2 years after a prescribed burn. Growth then returned to rates similar to that of trees in unburned areas. Although we did not determine yearly changes, we can report on the net change in growth 10 seasons postfire. Neither one or two burns nor the season of burn significantly altered the growth of those trees that survived 10 years after the initial 1997/1998 prescribed burn treatment.

The damage to a ponderosa pine crown as measured by the scorch proportion was more important in predicting subsequent pine growth than either season or repeated burning. We reported similar results when investigating pine mortality in Thies et al. (2006) where we also found that season of burn was not a significant predictor for mortality but that fire-caused damage was.

The precision of our measurements of core increments could have been increased by collecting cores and then drying, sanding, and counting the rings under a microscope. With increased precision of measurement we may have detected small differences in growth. However, by using the mean of two cores per tree and large sample sizes in each treatment (Table 2), we feel that our methods would detect biologically significant growth differences.

Conclusions

We conclude that, after accounting for the effect of crown scorch proportion from the initial fires, neither a single prescribed fire treatment in the spring or fall nor two fire treatments at 5-year intervals had a significant impact on growth of thinned ponderosa pine trees 10 years after the initial prescribed fire treatment. However, we did find an increase in growth during the second 5-year interval compared with the first 5-year interval after the fall burns. If this trend continues, growth differences may become a significant consideration when management decisions are made. Damage to the crown of ponderosa pines as indicated by crown scorch proportion as a result of prescribed fire is more important in predicting future growth than either season of prescribed burn or repeated prescribed burning.

This study was conducted by observing ponderosa pine trees treated by fall or spring prescribed fires in six stands in the southern Blue Mountains of Oregon. Care should be exercised in extrapolating the results and conclusions beyond this locale or to other species.

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