

Season of prescribed burn in ponderosa pine forests in eastern Oregon: impact on pine mortality*

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Abstract. A study of the effects of season of prescribed burn on tree mortality was established in mixed-age ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.) at the south end of the Blue Mountains near Burns, Oregon. Each of six previously thinned stands was subdivided into three experimental units and one of three treatments was randomly assigned to each: fall 1997 burn, spring 1998 burn, and no burning (control). Burns were conducted as operational prescribed burns. Trees within six 0.2-ha circular plots on each experimental unit were observed for four post-burn growing seasons to determine fire damage and to detect immediate and delayed mortality and occurrence of black stain root disease (BSRD). There were 5321 tagged ponderosa pines alive at the time of the burns. The percentage of ponderosa pine dying was higher after fall burns than after spring burns. Differences in percentages of fire-caused mortality may be because fall burns are inherently more severe than spring burns. Although present in many trees, BSRD appeared to have little impact on mortality. The lion's-tail appearance, thought to be a symptom of BSRD, was found to be an unreliable indicator of BSRD in the six test stands.

Additional keywords: black stain root disease; Blue Mountains; fire; *Leptographium wageneri*.

Introduction

Fire is an important consideration in understanding the ecology and management of ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.) and these links have been previously reviewed (Barrett 1979; Baumgartner and Lotan 1988; Agee 1993; Vance *et al.* 2001). Many ponderosa pine stands are currently past their historic fire return interval. These conditions are commonly attributed to decades of fire exclusion and suppression, timber harvesting, and historical periods of overgrazing (Weaver 1943; Covington and Moore 1994; Kolb *et al.* 1994). Heavy fuel accumulations and ample fuel ladders have put stands at risk for uncharacteristically severe wildfires. Prescribed burning currently is being used as a restoration and management tool to reduce fuel loading and stand densities and to restore fire to its historic disturbance role in western interior forests. Prescribed fire simulates the frequent low-intensity surface fires thought to be characteristic of the historic disturbance environment of low elevation forests throughout the interior west before non-indigenous

settlement (Weaver 1943; Agee 1993, 1996; Covington and Moore 1994). Managers are seeking broader treatment opportunities, including various seasons for prescribed burning, for vast acreages that would benefit from fuel reduction. More than one prescribed burn or a combination of mechanical treatment followed by burning may be necessary to adequately reduce fuels before fire can play its historic role in maintaining the ecosystem. The effects of seasonally different prescribed burning regimes on ecosystem structure are poorly understood. Managers need the ability to predict mortality after prescribed burning to better prepare burning prescriptions that will achieve management objectives, such as post-fire stocking levels. Managers also are concerned about the seasonal timing of stand treatments as it affects second-order fire effects, such as the potential response of insects and diseases and successional pathways. These knowledge gaps are important to development and implementation of fire management plans in the Blue Mountains of Oregon and beyond.

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Considerable effort has been devoted to predicting mortality of fire-damaged ponderosa pine. Comprehensive literature reviews of methods to study and predict fire-caused mortality of ponderosa pine in the western United States are available (McHugh 2001; Fowler and Sieg 2004). The effect of season of prescribed burn has received ample speculation, but little focused study. We are aware of only one adequately replicated experiment to test the impact of season of prescribed burn on ponderosa pine mortality (Harrington 1987, 1993).

Our study was designed originally to examine the effects of season of prescribed burn on mortality of ponderosa pine from black stain root disease (BSRD) caused by *Leptographium wageneri* var. *ponderosum* (T. C. Harrington & F. W. Cobb) T. C. Harrington & F. W. Cobb and its potential insect vector(s) (Cobb 1988; Hansen 1997). The study was expanded to examine three causes of tree mortality: BSRD, insects, and fire. This paper details the establishment of a long-term study of prescribed burning and reports fire-caused ponderosa pine mortality during the subsequent four growing seasons. The primary objective was to determine if ponderosa pine mortality is influenced by the season in which a prescribed burn is conducted in the southern Blue Mountains.

Methods and materials

Study sites

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 (Fig. 1). The six stands are in three locations designated as Kidd Flat, Trout, and Driveway, with one, one, and four stands, respectively. Kidd Flat and Trout are 18 km west of the Driveway area. Location, elevation, aspect, slope, and plant communities are given for the test stands in Table 1. Understory vegetation is an important indicator of site productivity as well as an important component of the fuels in a prescribed burn (Johnson and Clausnitzer 1992). The

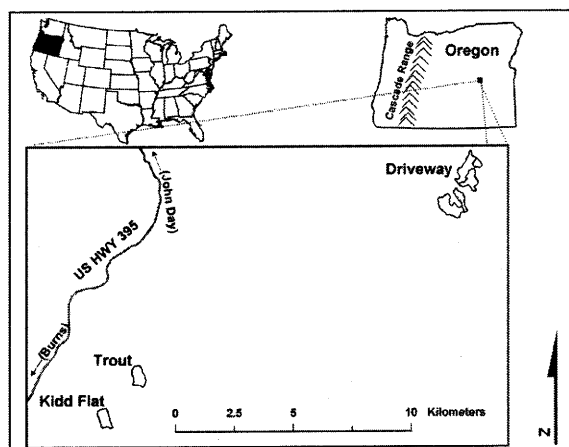


Fig. 1. Location of experimental units.

Table 1. Site and dominant pre-burn understory vegetation summary for the six study stands

Stand ^A	Lat/Long	Elevation (m)	Aspect	Slope ^B	Dominant grasses, forbs and shrubs ^C
D14	43°52'41"N/ 118°46'19"W	1570–1740	SW, SE	23% (2)	<i>Agropyron spicatum</i> (Pursh) Scribn. & Smith, <i>Carex rossii</i> Boott, <i>Sitanion hystrix</i> (Nutt.) Smith, <i>Collomia grandiflora</i> Dougl., <i>Crepis acuminata</i> Nutt., <i>Berberis repens</i> Lindl., <i>Chrysothamnus</i> Nutt. spp. ^D , <i>Artemisia tridentata</i> Nutt.
D17	43°52'53"N/ 118°45'57"W	1630–1700	SW	16% (2)	<i>Festuca idahoensis</i> Elmer, <i>Elymus cinereus</i> Scribn. & Merr., <i>Bromus carinatus</i> H. & A., <i>Sitanion hystrix</i> , <i>Eriogonum heracleoides</i> Nutt., <i>Crepis acuminata</i> , <i>Ribes cereum</i> Dougl., <i>Artemisia tridentata</i>
D26	43°53'25"N/ 118°45'35"W	1645–1725	SW, SE	16% (2)	<i>Bromus carinatus</i> , <i>Elymus cinereus</i> , <i>Stipa occidentalis</i> Thurb., <i>Sitanion hystrix</i> , <i>Erigeron corymbosus</i> Nutt., <i>Berberis repens</i> , <i>Ribes cereum</i>
D28	43°53'32"N/ 118°45'48"W	1700–1740	SE	15% (2)	<i>Festuca idahoensis</i> , <i>Sitanion hystrix</i> , <i>Bromus carinatus</i> , <i>Agropyron spicatum</i> , <i>Elymus cinereus</i> , <i>Eriogonum heracleoides</i> , <i>Artemisia tridentata</i> , <i>Chrysothamnus</i> spp. ^D
Kidd	43°47'39"N/ 118°57'5"W	1680–1730	E, N	7% (1)	<i>Carex geyeri</i> Boott, <i>Carex rossii</i> , <i>Sitanion hystrix</i> , <i>Lupinus caudatus</i> Kell., <i>Kelloggia galioides</i> Torr., <i>Arnica cordifolia</i> Hook., <i>Berberis repens</i> , <i>Prunus</i> L. spp. ^E , <i>Rosa</i> L. sp.
Trout	43°48'36"N/ 118°56'3"W	1640–1670	W, NW	14% (2)	<i>Carex geyeri</i> , <i>Stipa occidentalis</i> , <i>Thalictrum occidentale</i> Gray, <i>Kelloggia galioides</i> , <i>Berberis repens</i> , <i>Symphoricarpos</i> Duhamel spp. ^F

^AStands at Driveway are abbreviated (D).

^BData are means with standard errors in parentheses.

^CDominant understory vegetation based on cover, nomenclature based on Hitchcock and Cronquist (1973), after Kerns *et al.* (unpublished data).

^DSpecies are *Chrysothamnus nauseosus* and *C. viscidiflorus* and were not differentiated during sampling.

^ESpecies are *Prunus virginiana* and *P. emarginata* and were not differentiated during sampling.

^FSpecies are *Symphoricarpos albus* and *S. oreophilus* and were not differentiated during sampling.

study stands were selected from those already planned for prescribed burning at a time that met the study needs and where BSRD was known to be present from earlier surveys. Trees were generally between 80 and 100 years old with intermittent or frequent individuals of ~200 years (unpublished data from the Emigrant Creek Ranger District). 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 fire.

Climate is characterized by a short growing season with annual rainfall averaging 43 cm (based on the precipitation zone map found in Carlson 1974), most as winter snowfall. Summers are dry and diurnal temperatures fluctuate widely with hot days and cold nights. Winter temperatures are low, and snow can accumulate to considerable depths (Franklin and Dyrness 1973).

Soils in the Driveway area are well to poorly drained gravelly loams and clay loams derived from basalt, andesite, tuffaceous interflow, altered tuffs, and breccia materials. Soils at Trout are well to moderately well drained gravelly loams and clay loams derived from basalt, andesite, and tuffaceous interflow materials. Soils at Kidd Flat are well drained loams and gravelly loams derived from hard to very hard rhyolite. Soils are described more completely in a soil survey of the Malheur National Forest (Carlson 1974).

Experimental units and treatments

Each of the six stands was designated as a replicate and divided into three contiguous experimental units similar in stand type, aspect, and slope. Experimental unit boundaries were established along topographic features with consideration for control of the prescribed burns. Three treatments (no burning [control], fall burn, and spring burn) were randomly assigned to experimental units within each replicate. 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. Experimental units were burned in mid-October 1997 (fall burn) or mid-June 1998 (spring burn). Weather conditions at the time of the burns were similar for the two seasons: temperature, fall from 17°C to 21°C, spring from 16°C to 21°C; relative humidity, fall from 26% to 35%, spring from 30% to 40%; wind speed, fall from 5 km h⁻¹ to 6 km h⁻¹, spring from 3 km h⁻¹ to 11 km h⁻¹. All burns 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. Because of the timing of the burns, all 18 experimental units developed for the same number of growing seasons without further disturbance.

Sampling plots

Within each experimental unit, six 0.2-ha sampling plots were established post-fire: early June 1998 for no-burn and fall burned units and mid-July 1998 for spring burned units. The size and shape of the Trout no-burn unit limited installation to five plots, making a total 107 sampling plots. Sampling plots were installed at least 100 m apart in locations representative of the average stand and burn conditions within the experimental unit. Areas having few ponderosa pines, such as a rock outcropping or a thicket of mountain-mahogany, were avoided. Each plot center was marked with a metal pin and its location mapped. All standing conifers (except junipers), greater than 7.5 cm diameter at breast height (dbh) on each plot, were tagged.

Data collection

When sampling plots were established, the aspect (predominant direction the plot faces), percentage of slope, and area burned were recorded for each plot. Two individuals independently estimated the percentage of surface area burned in each plot to the nearest 5%, and a consensus percentage was recorded.

Each tree was evaluated and marked in July 1998 (1 month after the spring burn) as either alive (if the tree had some green needles) or dead (if all needles were scorched-discolored due to heat from the fire). Dead trees were categorized by time of death as pre-burn mortality (based on bark condition, presence of decay, and lack of needles and fine twigs), immediate mortality (alive at the time of the burn but dead by July 1998), and delayed mortality (died after July 1998 but before fall 2001). Only those living at the time of the prescribed burns were included in the analyses. Delayed mortality was recorded in fall 1998, 1999, 2000, and 2001; trees without any green needles, and not previously marked as dead, were recorded as having died that growing season. Dead trees were evaluated for BSRD by examining sapwood near the roots for stain characteristic of BSRD (Cobb 1988; Hansen 1997).

In fall 1998, the end of the first growing season after the prescribed burns, morphological variables were recorded for each tagged tree. The dbh of each tagged tree was measured to the nearest 0.25 cm on the uphill side of the tree at 1.37 m above mineral soil. The height of each tagged tree was measured to the nearest 3.0 cm with a laser rangefinder with inclinometer. Of the 5321 trees alive at the time of the burn, 75 trees had broken or damaged tops and were measured for dbh but not height. Missing tree heights were estimated using dbh and linear regression models. The linear models were built by using dbh and tree heights from live trees with undamaged tops. Natural logarithmic transformations of the response (height) and predictor (dbh) variables were applied to create the best fit for the linear regressions. To develop the most accurate estimates possible, a separate linear regression model was developed and used for each stand. Regression

Table 2. Mean percent and standard error (in parentheses, six replicates) of post-burn mortality of ponderosa pine by treatment at five observation times

Treatment	Alive at burn (n)	Total mortality (n)	Post-burn mortality: mean percentage of total ^A					Total mortality (%)
			1 Month	Fall 98	Fall 99	Fall 00	Fall 01	
No burn	1610	16	0	0.6 (0.3)	0.3 (0.2)	0	0.1 (0.1)	1.0 (0.3)
Fall	1922	619	8.2 (3.8)	11.8 (3.9)	8.5 (1.5)	0.5 (0.3)	0.1 (0.1)	29.0 (8.9)
Spring	1789	203	2.6 (0.7)	3.2 (0.9)	4.3 (1.2)	0.5 (0.2)	0.2 (0.2)	10.8 (2.3)
Burn subtotal	3711	822	6.7	8.2	6.6	0.5	0.1	22.1
Total	5321	838	4.6	5.9	4.7	0.4	0.1	15.7

^AImmediate mortality: found 1 month after the burns; delayed mortality, found in fall 1998, fall 1999, fall 2000, or fall 2001.

equations used to convert dbh to tree height had a coefficient of determination (R^2) varying from 0.75 to 0.98. For each tree, indicators of tree damage, such as needle scorch or bole scorch (blackening) or basal char (consumption of bark at the base of the tree), were noted. Note also was made of the number of quadrants around the base of each tree where the litter/duff was largely consumed. Two zones were recognized in fire-damaged crowns: green (presumed undamaged crown) and scorched (needles killed or consumed). By the end of the first growing season after the burn treatments, the scorched zone of some trees differentiated into an upper zone of regreen, where new needles had started to develop, and a lower zone of branch kill, where the fire was hot enough to kill or consume needles and buds.

Two crown indicators of poor tree health were recorded:

- (1) Thin crown, or fewer needles than normal, a subjective judgment based on comparison with healthy appearing trees. This is generally accepted to indicate a tree that is stressed and often is associated with root disease.
- (2) 'Lion's-tail' or 'tufted' appearance, defined as a tuft of significantly shorter than normal needles at the branch tips of ponderosa pine as seen on most of the branches in at least the upper third of the crown. Such needles are usually on the terminal 5 cm of the branches but may extend back 13 cm; most needles will be only ~75% of normal length, and the tufts are composed of 4–5 years of reduced branch growth (Kelsey *et al.* 1998). It is generally assumed that trees with crowns showing lion's-tail symptoms have BSRD (Cobb 1988).

Data analysis

All statistical analyses were conducted using S-PLUS 2000 (Mathsoft 1999). Pre- and post-burn tree and stand characteristics were analysed by using an analysis of variance (ANOVA) model for a randomized complete block design with six blocks (stands) and three treatments (fall and spring burn and no-burn control). Values of tree variables as measured in fall 1998 were used for trees before burning and for trees still alive after burning. Post-burn evaluations included only trees that survived at least four growing seasons (still alive in fall 2001). The variables assessed by ANOVA

pre- and post-burn included dbh, tree height, trees per hectare, basal area, and percentage of the plot area burned. Treatment differences were tested for proportion of the area burned, proportion of trees that died (immediate, delayed, and total mortality), proportion of the trees with BSRD, crown scorch, regreening, and the litter/duff consumption. An arcsine square root transformation was needed to stabilize the variance and satisfy the assumptions of ANOVA for the proportion data (Sokal and Rohlf 1980).

Results

Prior to prescribed burning there were 5321 live trees (Table 2) on the 107 plots. At the first post-fire examination of the stands, ~1 month after the spring burns, 278 trees had all needles consumed or scorched; all were presumed to be dead. At the end of the first growing season after the burns (fall 1998), however, 30 of the trees with all needles consumed or scorched were found to have regreened (sprouted needles) on some proportion of the upper crown. These 30 were included with trees that survived the burns, thereby leaving 248 tagged trees designated as immediate mortality and 5073 trees that were alive after the fire.

There was no significant difference between the pre-burn treatment means for dbh ($P = 0.8725$), tree height ($P = 0.9320$), trees per hectare ($P = 0.6825$), or basal area ($P = 0.8112$). An overview of changes in stand structure resulting from the prescribed burns can be gained from a comparison of the pre-burn and post-burn variable means (Table 3). Comparison data were from trees measured in fall 1998; pre-burn data were from all live trees. Post-burn data were from trees still alive in fall 2001. Analyses of tree characteristics four seasons post-burn found no evidence of significant changes in stand structure as a result of burning. There was no evidence of a significant difference between the treatment means for dbh ($P = 0.7531$), tree height ($P = 0.5338$), trees per hectare ($P = 0.3640$), basal area ($P = 0.1021$), or percentage of each plot that burned ($P = 0.9635$) (Table 3).

By fall 2001, 838 trees had died following the burns: 248 trees with immediate mortality and 590 with delayed mortality. There is no evidence of a difference in the median

Table 3. Pre- and post-burn means and standard errors (in parentheses) of stand and tree size characteristics
Data collected fall 1998

Stand name	dbh (cm)		Tree height (m)		Trees per ha		Basal area (m ² /ha)		Experimental unit		
	Pre-burn	Post-burn	Pre-burn	Post-burn	Pre-burn	Post-burn	Pre-burn	Post-burn	Area (ha)	Burned (%)	Slope (%)
DW 14	25.0 (1.8)	27.0 (0.3)	13.7 (0.4)	14.5 (0.4)	328 (62.4)	252 (2.4)	19.4 (0.5)	17.6 (0.7)	18.4	51	23
DW 17	29.7 (0.3)	31.0 (0.8)	14.4 (0.3)	15.0 (0.6)	212 (13.5)	181 (16.9)	18.2 (1.0)	16.5 (0.9)	6.3	78	15
DW 26	28.1 (2.1)	29.8 (1.6)	14.7 (1.1)	15.5 (1.2)	263 (25.9)	189 (42.1)	19.1 (0.1)	15.3 (3.4)	14.5	69	16
DW 28	30.8 (3.7)	31.8 (3.9)	16.3 (1.4)	16.5 (1.4)	215 (58.1)	186 (52.9)	18.7 (0.6)	16.8 (1.5)	15.9	63	15
Kidd	25.4 (1.0)	25.5 (0.9)	12.2 (0.7)	12.2 (0.6)	248 (38.7)	240 (37.5)	17.7 (1.6)	16.9 (1.4)	11.2	27	14
Trout	27.9 (1.9)	28.6 (2.3)	13.5 (1.0)	13.8 (1.2)	203 (14.7)	189 (17.6)	17.2 (1.8)	16.7 (2.0)	12.8	51	7
Treatment											
No-burn	28.9 (1.6)	29.0 (1.6)	14.2 (0.8)	14.2 (0.8)	226 (17.9)	224 (17.7)	18.0 (0.8)	17.9 (0.8)	9.4	NA	14
Fall	28.0 (2.4)	30.2 (2.3)	14.3 (1.1)	14.3 (1.1)	264 (43.8)	178 (28.2)	18.4 (0.5)	14.4 (1.2)	15.1	56	18
Spring	27.7 (1.0)	28.7 (1.2)	13.9 (0.4)	14.3 (0.5)	246 (25.7)	218 (21.1)	18.4 (1.0)	17.6 (0.9)	15.1	57	14

proportion of immediate mortality based on season of burn ($P = 0.1532$). The proportions are 0.03 and 0.10 for spring and fall, respectively. There is evidence of a difference in the median proportion of delayed mortality based on season of burn ($P = 0.0397$). The proportions are 0.09 and 0.22 for spring and fall, respectively. There is suggestive evidence for a difference in the median proportion for total mortality based on season of burn ($P = 0.0679$). The proportions are 0.11 and 0.32 for spring and fall, respectively. Because the annual rate of mortality at the burned experimental units appeared to drop after four growing seasons to about that of the unburned experimental units, we assumed for our analyses that the mortality detected in fall 2001 represented the end of the fire-caused mortality (Table 2). Of the delayed mortality observed in the burn treatments, 96% had occurred by the end of the second growing season. Of the 30 trees initially recorded as dead (8 and 22 trees in the fall and spring burns, respectively) but later classified as regreened, 20 were still alive in fall 2001 (4 and 16 trees in the fall and spring burns respectively). Of the 10 regreened trees that died, 5 had BSRD.

Observations made on the plots and trees provide evidence of the coverage and intensity of the burns. While the percentage of plot area burned had means of 56% and 57% for fall and spring burns, respectively (Table 3), the fuel mound at the base of burned trees caused bole scorch and basal char on 99% and 94% of the trees in the fall and spring burns, respectively. Complete consumption of litter and duff was observed near the base of trees on an average of 2.8 and 1.0 quadrants as a result of the fall and spring burns, respectively, with strong evidence for a difference between the two seasons of burn ($P < 0.0001$). Although the percentages of trees with crown scorch were 56% and 37% for the fall and spring burns, respectively, there was no evidence that the season of burn affected the proportion of trees with crown scorch ($P = 0.1927$). Of those trees experiencing crown scorch, a smaller percentage of trees in the fall burn (37%) experienced regreening than those in the spring burn (67%) ($P = 0.0911$).

Figure 2 shows the size distribution of trees alive at the time of the burn and those that died by fall 2001 for both the

fall and spring prescribed burns. Both fall and spring burns created a thinning from below (higher sensitivity of small trees to fire), as was expected.

All tagged trees that died (Table 2) were evaluated for the presence of BSRD (Table 4). There is no evidence that the median proportion of trees that died with BSRD was affected by treatment ($P = 0.3021$). The proportions of trees that died with BSRD in the no-burn, fall, and spring treatments were 0.375, 0.181, and 0.389 respectively.

The proportion (percentage) of dead trees with BSRD was similar for pre-burn, immediate, or delayed mortality. There were 99 trees on all plots that died between 1995 and the burns (pre-burn mortality); 25 had BSRD, or ~25%. The pre-burn data give an indication of the BSRD associated with mortality but likely are underestimates. BSRD becomes difficult to identify 1 or 2 years after the tree dies, so BSRD may have been present more often than was recorded. Of the 248 trees recorded as immediate mortality, 55 had BSRD, or ~22%. Of the 574 trees recorded as delayed mortality (through 2001), 136 had BSRD, or ~24%.

Records of trees with BSRD were examined for evidence of unthrifty crowns. Of the 197 dead trees having BSRD, only 2 were recorded as having the crown symptom known as lion's tails. Although the data are not easily analysed statistically, of the 16 post-fire live trees with thin crowns, only 8 died through 2001 and 2 of those had BSRD. Of 11 post-fire live trees with lion's-tail symptoms, 2 died through 2001 and both had BSRD.

Discussion

This study demonstrated that mortality of ponderosa pine in prescribed burns in the southern Blue Mountains of Oregon is related to season of burn. Contrary to other studies of ponderosa pine, we found evidence for higher mortality after a fall prescribed burn than after a spring prescribed burn. Other studies (Harrington 1987, 1993; Swezy and Agee 1991) found slightly higher mortality following spring or summer prescribed burns than from burns conducted in the fall. Wagener

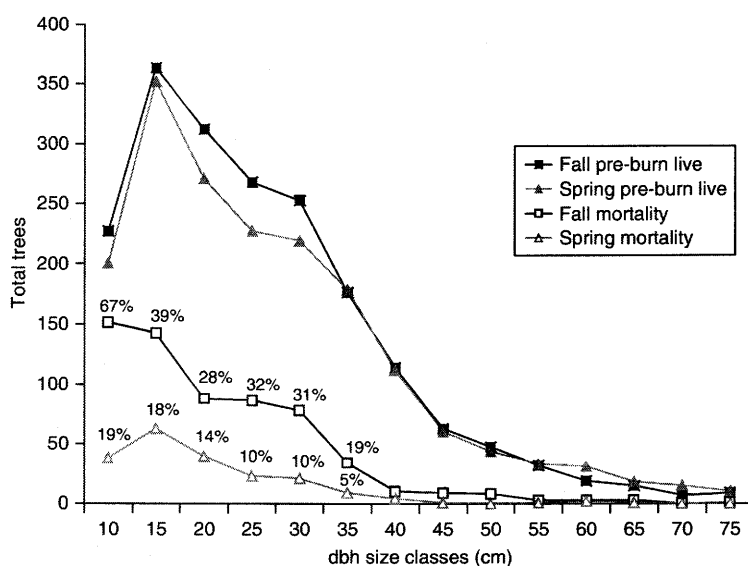


Fig. 2. Frequency by dbh size class of pre-burn live trees and post-burn mortality by season of burn. Live trees include all burn treatment trees alive at the time of the prescribed fires ($n = 3711$). Post-burn mortality includes both immediate mortality and delayed mortality through fall 2001 ($n = 822$). The percentage of mortality for smaller diameter classes is provided. dbh, diameter at breast height.

Table 4. Dead trees with black stain root disease (BSRD), by treatment, at six observation times

Treatment	Dead pre-burn		Post-burn mortality with BSRD					Total	Total post-burn mortality (%)
	Total	BSRD	1 Month	Fall 98	Fall 99	Fall 00	Fall 01		
No burn	46	14	NA	3	1	0	2	6	37.5
Fall	19	4	34	9	67	2	0	112	18.1
Spring	34	5	21	14	43	1	0	79	38.9
Burn subtotal	53	9	55	23	110	3	0	191	23.2
Total	99	25	55	26	111	3	2	197	23.5

(1961) and Dieterich (1979) evaluated mortality of ponderosa pine from wildfires and concluded that fires early in summer cause more mortality than fires late in summer. These studies differ greatly from our study and from each other in location, annual precipitation, study design, sample size, stand age, and variables measured.

The mechanism responsible for seasonal differences in tree mortality can be explained by seasonal phenology differences or by seasonal fire intensity and fuel consumption. Harrington (1987) attempted to normalize fire effects to examine phenology differences by selecting sample trees in particular crown-scorch/dbh classes from different seasons of burn. Swezy and Agee (1991) determined that phenology is important in explaining more growing season mortality. Many reports suggest that bud phenology best explains seasonal differences in mortality (Wagener 1961; Dieterich 1979; Wyant and Zimmerman 1983; Harrington 1987; Swezy and Agee 1991). However it is intuitive that, if intensity is

sufficiently greater in one season, then it could dominate the results, regardless of phenology. It is not obvious how much greater intensity is required to override possible phenology factors that might exist.

Fire intensity was not evaluated directly, but we speculate that seasonal differences in tree mortality observed in this study were the result of small differences in seasonal fire intensity. Although the following fuel and tree damage observations may not all differ greatly between seasons, taken together they provide evidence that fall burns were somewhat more intense than the spring burns:

- (1) More of the fuel mound around each tree burned completely in fall (2.8 quadrants) than in spring (1.0 quadrants);
- (2) A larger percentage of trees experienced some crown scorch as a result of the fall burns (56%) than as a result of spring burns (37%);

- (3) Of the trees that experienced crown scorch, a smaller percentage were able to regreen after the fall burn (37%) than after the spring burn (67%), thus indicating a more intense fire killing more buds in fall;
- (4) Of the trees that experienced complete crown scorch, then regreened and survived four growing seasons, fewer were in the fall burns (4) than were in the spring burns (16); and
- (5) There was more immediate mortality (total crown scorch) associated with fall burns (10%) than with spring burns (3%).

Fire managers reported weather data for the time of the burns, but the data suggest that weather was similar enough between the fall and spring burns to not be a factor in the seasonal differences in fire effects. We speculate that even though the amount of fuels on the treatments was the same, that the seasonal differences in fuel moisture (caused by higher temperatures and lower humidity during the summer) would account for a more intense fall burn, thus explaining the observed tree damage.

We hypothesize that, although many trees in the test stands have BSRD, the annual mortality rate is very low. The proportion of dead trees with BSRD is similar for pre-burn, immediate mortality and delayed mortality. The trees having immediate mortality were killed directly by the fire. In the absence of a better sample, we will use the proportion of immediate mortality with BSRD (22%) as an estimate of the proportion of all trees in the stands that have BSRD. If 22% of the trees on the no-burn units have BSRD, there are 354 infected trees on the no-burn units. After four seasons, six dead trees on the no-burn units had BSRD, an average annual mortality rate for infected trees of less than 0.5%. Even this small rate may be an overestimate because trees with infected roots would have been missed by an examination limited to the lower bole. The percentage of infected trees thus could be much higher. If BSRD has been a part of this ecosystem for a long time, and we have no evidence to the contrary, we conclude that BSRD takes a very long time to kill the ponderosa pines in our test stands. Alternatively, in our test stands, BSRD may not be a primary killer of trees. Because the fungus causing BSRD plugs vessels and reduces water transport in pine trees (Cobb 1988; Joseph *et al.* 1998; Kelsey *et al.* 1998), we presume that the disease generally reduces the ability of trees to recover from fire injury and therefore will contribute to the post-fire mortality in the stand regardless of season of burn.

Results from this study did not support use of the lion's-tail symptom as a useful indicator when surveying for BSRD. Reduced terminal or branch growth and increased needle density give foliage at the end of branches a tufted or lion's-tail appearance (Cobb 1988). Differences in years of needle retention do not contribute to the lion's-tail appearance. In stands adjacent to the study area, Kelsey *et al.* (1998) found that retention of ponderosa pine needles on lateral branches

ranged from 4 to 5 years regardless of the presence of BSRD. Further, they found that the lion's-tail symptom provided good separation between severely diseased (BSRD) and healthy trees. In our study, 11 trees had lion's-tail symptoms and 2 died with BSRD. Although both trees that died with this symptom had BSRD, 195 died that had BSRD but without this symptom. So even though all trees with lion's-tail symptoms may have BSRD, only a small proportion of trees with BSRD developed lion's-tail symptoms thus making it a poor choice for a survey tool.

To determine whether management objectives will be achieved by using prescribed fire, operations managers need to be able to predict the death of individual trees from visible fire injury (delayed mortality). We recognized two temporal categories for tree mortality: immediate and delayed. Immediate mortality is a result of direct killing of tissues by application of heat and is recognized as trees without green needles within a month of the burn. Had we used this criterion as a marking guide a month after the burns, the immediate mortality would have been marked correctly 93% of the time. By the end of the first growing season after the burns (fall 1998), 67% of the total mortality could be identified, and 30 trees marked as immediate mortality were still alive and had regreened. Delayed mortality is caused by physiological processes set in motion by the fire that will result in death of tissues and eventually death of the tree. These changed processes may expose the trees to secondary causes of mortality, such as bark beetles or other insects.

Diameter at breast height is an easily measured indicator of tree size and is correlated with total height, bark thickness, volume of crown, and height of the crown above the ground. Thus, stem diameter not only directly reflects a tree's relative resistance to cambium damage but also is an important indicator of resistance to (or avoidance of) crown damage. Models predicting ponderosa pine mortality typically use a measure of tree size and a measure of fire damage as variables that can predict tree mortality. Our results (Fig. 2) were consistent with previous research that found increasing dbh predicted increasing resistance to mortality from fire (Harrington and Hawksworth 1990; Saveland *et al.* 1990; Harrington 1993; Regelbrugge and Conard 1993; Finney 1999; Stephens and Finney 2002; McHugh and Kolb 2003). But Finney (1999), working with data from wildfires in ponderosa pine, found that after 4 years the largest and smallest trees had the highest probability of dying. Ryan and Frandsen (1991) found a similar relationship and hypothesized that the increase in fuel at the base of mature ponderosa pine increases with diameter, and the extended heating from combustion of the larger fuel mounds results in greater cambium mortality. Our study differed from Finney (1999) in that we examined prescribed burns which likely were cooler and generally did not completely consume the fuel mounds around the larger trees. Our study differed from Ryan and Frandsen (1991) in that the 19 trees they examined generally were larger than the largest

trees in our study. We did not observe larger trees being more likely to die as a result of prescribed burns.

Crown scorch and branch kill are different measures of crown damage. Crown scorch reflects the proportion of the crown in which needles are killed by the heat from a surface fire but not consumed. Branch kill reflects the proportion of the crown in which the heat kills both the needles and branch buds, a far more serious injury to the tree (Wagener 1961). Surviving buds amongst scorched needles are not evident until the next bud break occurs. For the stands reported here, all regreening occurred by the end of the growing season after the burn. Additional regreening was not observed in subsequent growing seasons. This has two potentially important management implications:

- (1) If it is important to minimize cutting trees that otherwise would survive, then decisions must wait until the buds have expanded and the needles are visible from the ground – in this study that happened by the end of the first growing season after the fire; and
- (2) Superior ability for buds to tolerate heat may be an important selection criterion for identifying desirable genetic stock – perhaps larger buds, owing to their greater thermal mass, would better survive the heat of a fire.

Conclusions

This study was conducted by observing ponderosa pine in areas treated by fall or spring prescribed burns from six stands in the southern Blue Mountains of Oregon. Care should be exercised in extrapolating our results and conclusions beyond this locale or to other species. We draw the following general conclusions from this study:

- (1) The percentage of ponderosa pine mortality was higher after fall prescribed burns than after those in spring.
- (2) Season of prescribed burn had an effect on survival of ponderosa pine as it influenced fire intensity and burn severity.
- (3) Lion's tail, a purported symptom of BSRD, was not a reliable predictor of BSRD incidence.

Epilogue

The original plots and trees are being monitored and the study is ongoing. The experimental design, established burn units, and variables being monitored provide a unique opportunity to also examine burn interval. We bisected each experimental unit and randomly selected one subunit of each pair to be burned 5 years after the initial burn; the second subunit will be used to test a longer interval of burn (currently proposed to be 15 years). The season of burn for each subunit will remain the same as in the established study. The 5-year burns were successfully conducted and resulted in two additional treatments (burns in fall 1997 and 2002, and burns in spring 1998 and 2003) on each of the six replicates. The authors invite others to participate in developing additional

collaborative studies that use this established, well replicated study platform.

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