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Fall Rates of Prescribed Fire-Killed Ponderosa Pine

Michael G. Harrington

The Author

Michael G. Harrington received his B.S. degree in forest science in 1970 and M.A. degree in fire ecology in 1977 from the University of Montana. He assisted in fire effects research intermittently at the Northern Forest Fire Laboratory from 1968 until 1977. In 1977, he became a Research Forester with the fire effects project in the Rocky Mountain Forest and Range Experiment Station in Tempe and later in Flagstaff, AZ. While with Rocky Mountain Station, he conducted prescribed fire application and effects research in Arizona and Colorado ponderosa pine forests. He transferred to the Intermountain Fire Sciences Laboratory, Intermountain Research Station, Missoula, MT, in 1987 where he currently is conducting research on the use of silviculture and fire in forest health restoration.

Research Summary

Prescribed underburning was carried out in three seasons in a second-growth ponderosa pine stand in southwestern Colorado. After burning, 526 trees with various levels of crown scorch were tagged and surveyed annually for 10 years to evaluate mortality and subsequent tree fall. Of the 123 dead trees, 75 percent fell within the study period. Even though a smaller percentage of autumn-killed trees fell than spring- or summer-killed trees (62 percent versus 78 percent), the difference was not significant. Fall rate differences were not noted among trees from 2 to 16 inches d.b.h. Two factors stood out as significant in evaluating tree fall differences following fire mortality: percent crown scorch and length of time between fire injury and death. Trees that died with greater than 80 percent crown scorch had about an 80 percent probability of falling within the 10 years regardless of length of survival after injury. Trees that died from less than 80 percent crown scorch and that died within the first postburn year had a 75 percent probability of falling. However, trees that died from less than 80 percent crown scorch but that survived for 2 or 3 postfire years had a 27 percent probability of falling. Even though this study was relatively short, these findings have significance for those concerned about the quality of standing dead trees for wildlife habitat and about the rate of down, woody fuel build-up after prescribed burning.

Intermountain Research Station
324 25th Street
Ogden, UT 84401

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The immediate, visible impacts of forest fires can vary from partial consumption of the surface litter and minimal plant charring to high consumption of all fuel classes and complete mortality of large stands of trees. When fire passes through a stand, trees can be killed outright if all or a large portion of the foliage, buds, and branches are killed, or they can be mortally wounded if a smaller portion of the living tissue is killed. Trees in this latter group will die over several years subsequent to the fire with the mortality rate generally decreasing over time. Another category includes trees whose vigor has been reduced by fire injury, thereby permitting successful insect and disease attacks, which commonly result in tree death.

Standing dead trees have distinctly different influences on ecosystems than living trees do. In the first half of this century, snags were primarily thought of as fire hazards (Dahms 1949; Keen 1955). Management activities at that time included felling dead trees in timber sales and along roads. More recently, managers have realized the economic and ecological value of snags. Products with direct economic value include house logs, firewood, and even lumber (Lyon 1977). As decay spreads within the tree, these values diminish and are generally lost when the tree falls.

Apart from economics is the value of standing dead trees for wildlife habitat. Birds use such trees to perch, feed, nest, overwinter, and hide (Bull 1978). Mammals also use snags to nest or den, feed, and overwinter. The value of dead trees for habitat dramatically changes when standing trees become fallen logs because bird nest and perch use is greatly reduced. These logs, however, are important for hiding and thermal cover, feeding, and nesting for ground birds (grouse) and small mammals (rabbits and squirrels) (Thomas and others 1979). As they decay, logs also ameliorate soil moisture and nutrient condition for plant growth (Harvey and others 1988).

Dead trees are also an important forest fuel. They ignite more easily than live trees and, therefore, represent a higher potential source of burning embers that can aid wildfire spread. After falling, logs represent a potentially high concentrated heat source causing problems for fire suppression and sometimes resulting in microsite soil degradation.

Knowledge of the transition rate from standing dead trees to fallen logs would be important for those who manage timber and soil resources, wildlife habitat, and wildland fuels. Others have reported on the fall rate of beetle-killed ponderosa pine (*Pinus ponderosa*) (Keen 1955; Schmid and others 1985), beetle- and fire-killed Jeffrey pine (*Pinus jeffreyi*) and white fir (*Abies concolor*) (Raphael and Morrison 1987), and fire-killed lodgepole pine (*Pinus contorta*) (Lyon 1984).

This study describes 10 year fall rates of second-growth ponderosa pine following mortality from different levels of crown scorch sustained in different seasons of prescribed burns.

Study Site

This research was conducted on the San Juan National Forest in southwestern Colorado on a southern aspect at 7,600 ft elevation. The nearly pure ponderosa pine stand averaged 124 square feet of basal area and 300 trees per acre with about 75 percent occurring in the 4- to 11-inch diameter at breast height (d.b.h.) range. Gambel oak (*Quercus gambelii*), which dominated the understory, averaged about 2 to 4 ft tall. The nearest weather station, 5 miles to the southwest at a similar elevation, receives an annual average of 17 inches of precipitation. The least precipitation falls in the late spring and the greatest in mid-summer.

Methods

This research was established initially to compare the impacts of prescribed burning in three distinct seasons on understory Gambel oak, which is a highly competitive, aggressive sprouter in this region. Fire treatments were applied in the autumn, late spring, and mid-summer. A description of pine phenology corresponding with these three seasons follows: entering dormancy in late October (autumn), during bud break with emerging foliage in early June (late spring), and during the moist, growing season in mid-August (mid-summer). Fires were applied at 2- and 4-year intervals over 8 years in an attempt to suppress oak sprouts. Burn conditions and oak response have been detailed in Harrington (1985). In general, air temperatures during burning were 10 to 15 °F cooler in the autumn burns, rates of fire spread were slightly higher in the spring burns, but flame lengths and fuel consumption were similar in all three seasonal treatments.

Fire injury to the pine stand became evident within a few weeks of the initial burns with the appearance of variable crown scorch. Crown scorch is defined as the percentage of live crown length that experienced foliage kill. An evaluation of this injury was made at that time. In 18 units of 2.5 acres each (six for each of the autumn, spring, and summer treatments), an attempt was made to locate and tag two trees in each of 20 size class/scorch class categories. The approximate midpoints and range of the four d.b.h. size classes were 3 (1.5 to 4.5), 6 (4.6 to 7.5), 9 (7.6 to 10.5), and 12 (10.6 to 15.0) inches. The approximate midpoints and range of the five crown scorch classes were 30 (20 to 40), 50 (40 to 60), 70 (60 to 80), 90 (80 to 99), and 100 percent. Burn treatments at 2- and 4-year intervals after the initial treatment caused little or no additional scorch or bole damage because the only fuel consumed was the litter deposited since the last burn. Therefore, virtually all of the evaluated crown damage resulted from the initial fire treatments.

A total of 526 trees were tagged and checked annually for vitality and, following death, to see if they had fallen. In the autumn treatment, 180 trees were chosen, 162 in the spring treatment, and 184 in the summer treatment. This report evaluates tree fall subsequent to mortality over that decade.

Analyses

Cumulative tree fall percentages were calculated by dividing the total number of trees that had fallen up to the end of a particular year by the number of dead trees. Not only did tree fall numbers increase over the 10-year study, but the number of dead trees also increased. This represented an increasing pool from which trees could fall.

Annual fall rates were calculated by dividing the number of trees that came down in a year by the number of standing dead trees at the beginning of that year. For each year, the number of trees that could possibly fall (standing dead) was reduced by the number that previously fell and was increased by the number that recently died. Average annual fall rates for a particular seasonal treatment, scorch class, or size class were calculated by averaging annual tree fall rates over the length of the study.

In the figures, mortality rates are shown along a time scale that is "Year After Fire," whereas the cumulative tree fall percentages are shown along a more appropriate time scale, "Year After Death." Because trees fell as a consequence of mortality, the "Year After Death" scale starts all trees at a point when they can begin falling.

A logistic regression analysis was run for these binomially distributed data to determine which of several factors were significant in explaining differences in total tree fall. Factors tested were season, tree size, scorch class, and number of years between fire injury and mortality. The Statistical Analysis System/Insight software (SAS 1993) was used to identify the significance of individual factors and appropriate interactions. Each dead tree was classified by season of treatment, d.b.h. class, scorch class, years alive after the fire, and a dummy dependent variable to indicate a standing or fallen condition. Tree fall probabilities were computed for each level of all significant factors and factor interactions. A 10 percent significance level was chosen.

Results

Harrington (1993) reported the 10-year fire mortality results on these research units. Because rates of tree fall are dependent on mortality rates, pertinent mortality results will be reviewed.

For combined seasonal treatments, 23 percent of the 526 tagged trees were dead by the 10th postfire year. Trees scorched in the active growing season were more likely to die than those in the dormant season. The spring treatment lost 28 percent and the summer treatment lost 30 percent compared to a 12 percent loss of the autumn-damaged trees. Even though most mortality occurred during the first 3 or 4 years, additional trees died over the next several years (fig. 1a), which is typical following underburning.

Besides season, other variables that affected mortality and could influence tree fall were tree size and degree of crown scorch. A greater percentage of smaller trees died than larger trees, with 40 to 50 percent mortality of trees less than 7.5 inches d.b.h. compared to less than 10 percent mortality for larger trees.

Increased crown scorch did not result in higher mortality until scorch exceeded 80 percent. Below this threshold, mortality averaged about 10 percent, but increased threefold to sevenfold above it. Again, after high first-year mortality, trees continued to die at a decreasing rate for several years (fig. 1b).

During the third postburn year, the first fire-killed tree fell; it was in the summer treatment. In year 4, eight more trees in that treatment were down. In the spring treatment, nine trees were first found down in year 4. No trees fell in the autumn treatment until year 5 when one tree was down. Five additional trees fell in year 6. Tree fall continued intermittently in all treatments to the end of the study.

Fallen trees had broken off within 1 ft of the ground where decay was prevalent.

Of the 123 tagged, dead trees, 92 (75 percent) fell during the 10-year study. Fallen trees had sustained an average crown scorch of 86 percent, which was

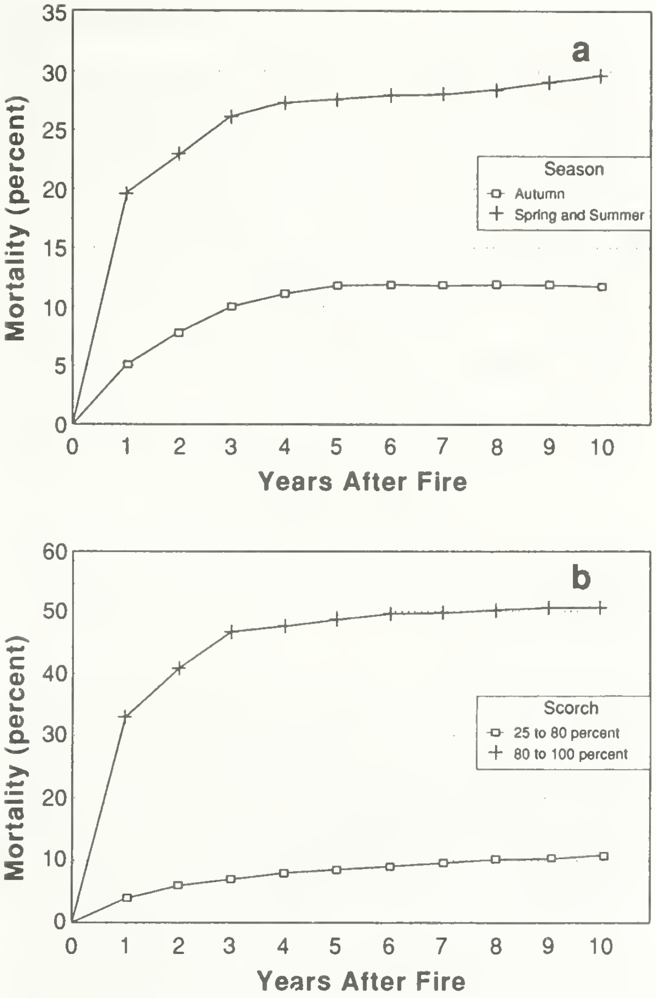

Figure 1—Cumulative mortality by (a) season of fire injury (autumn or spring and summer) and (b) crown scorch class.

significantly higher ($p < 0.07$) than the 73 percent scorch sustained by dead trees still standing. Average d.b.h. of standing trees (5.8 inches) was not significantly different from that of fallen trees (5.2 inches). However, 75 percent of the fallen trees died in the first postburn year, compared to 55 percent of the standing dead.

Over the 10-year study, 62 percent of the dead trees in the autumn treatment fell compared to about 78 percent in the combined spring and summer treatments. Because the spring and summer burns were growing season treatments, the cumulative and annual fall rates, which were similar, were combined. Figure 2 shows cumulative tree fall percentages for the seasonal treatments by year after death. The autumn treatment had a highly variable 12 percent average annual tree fall rate with the others averaging about 18 percent annually. The high variability in the autumn treatment was due to low fall rates in each of the first 3 years and last 3 years separated by higher rates in the middle years, including a large increase for trees dead 6 years. An important seasonal contrast is shown as the cumulative fall rate for trees dead longer than 6 years increased by only 5 percent for autumn-killed trees compared to 18 percent for the others.

Even though tree fall differences were indicated graphically among seasons of injury, significant differences were not found ($p > 0.30$) through regression analysis. Small sample sizes and high variability likely contributed to the lack of statistical significance.

Figure 3 illustrates cumulative tree fall by diameter class. Because only eight trees in the largest d.b.h. class (midpoint 12 inches) died, these were pooled with the 9-inch class to make a 10.5-inch class. The fall rate pattern for the 3-inch class was consistent throughout the study. Even with a slight decrease in fall rate in the other two sizes after years 6 or 7, the average annual rates among size classes were similar, ranging from 14 to 19 percent. Total tree fall percentages were not statistically different ($p > 0.25$) among size classes, ranging from 65 percent for the largest trees to 78 percent for the smallest.

Contrasting fall rates were noted between trees that died as a result of different levels of crown scorch. Because of small numbers of dead trees in the lower scorch classes (30, 50, and 70 percent) and similar mortality among them, numbers of downed trees in these classes were pooled and contrasted with pooled values in the two highest scorch classes (90 and 100 percent) (fig. 4). The annual fall rates of trees that died following low scorch was slightly greater than for the other scorch class for years 2 and 3. However, for the next 6 years, the fall rate of the lower scorched

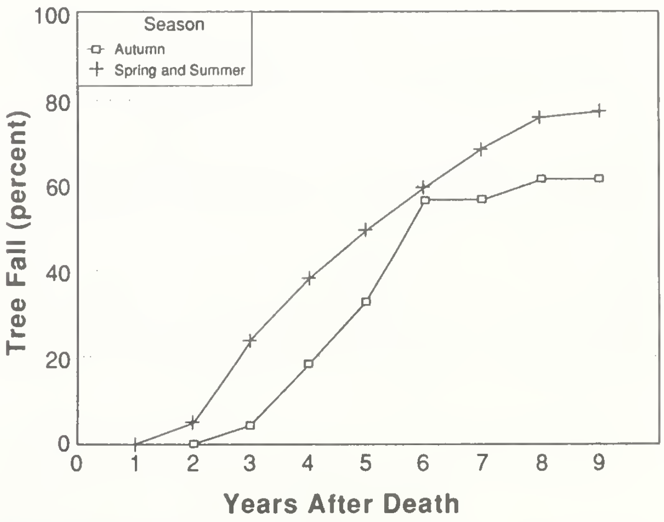

Figure 2—Cumulative tree fall by season of fire injury.

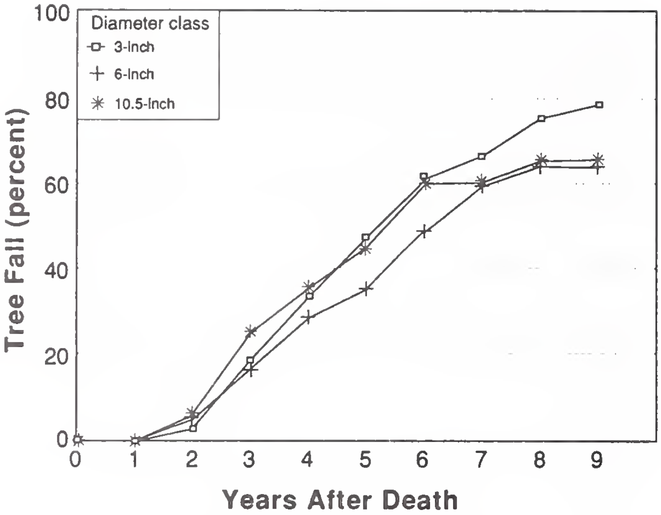

Figure 3—Cumulative tree fall by diameter size class.

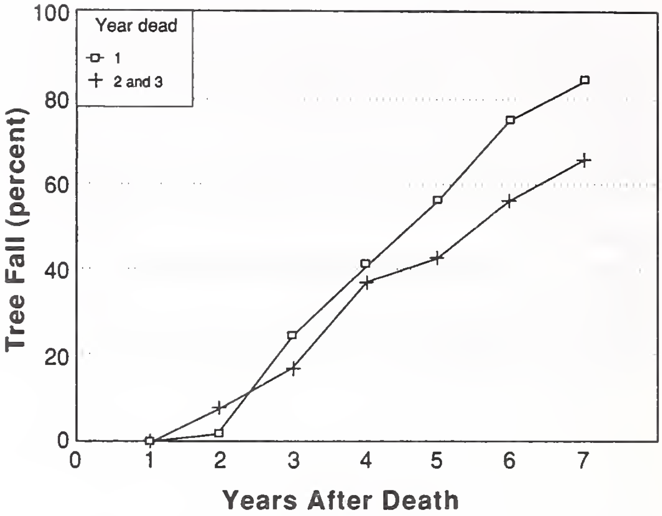

Figure 5—Cumulative tree fall by time between injury and death.

trees decreased to an average of 6 percent per year, compared to a rather constant rate of about 13 percent for the highly scorched trees.

Tree fall also varied by year dead after the fire, shown in figure 5 for trees that died in the first 3 postburn years. Data for trees surviving until the second and third year after injury were combined because tree fall percentages were similar. Comparisons could only be made through 7 years after death because trees dead in year 3 would only have 7 years to fall before the end of the study. Therefore, for equal comparison, falling of trees dead in year 1 was only considered until year 8, and falling of trees dead in year 2 was only considered until year 9. Results indicate that the longer the trees survived after mortal injury, the less the chance of early falling. Seven years after death, 85 percent of the trees that died in the first postburn year had fallen, compared to 65 percent of those that died in the second year, and 60 percent of those that died in the third year. Average annual fall rate for trees killed in the first postburn year was 26 percent, 19 percent for the second postburn year, and 14 percent for the third postburn year.

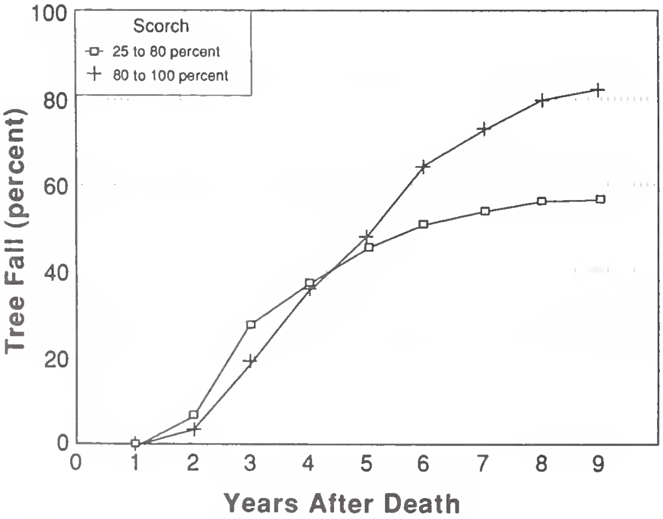

Figure 4—Cumulative tree fall by crown scorch class.

Analysis of the crown scorch variable indicated that 82 percent of the trees that died from high crown scorch fell, which was significantly greater ($p < 0.04$) than the 56 percent tree fall for those that died as a result of low scorch (fig. 4). Also, the 85 percent tree fall for those that died the first postburn year was significantly greater ($p < 0.08$) than the 67 percent total tree fall for those that died in the second or third postburn years (fig. 5). Analysis of the interaction of these two variables gives further insight into the importance of each for probability of tree fall, as the following tabulation shows:

	Years surviving after fire	
Scorch	**1**	**2+3**
Low	0.75	0.27
High	0.82	0.77

The 27 percent fall probability for trees that died from low crown scorch but that survived 2 to 3 years after the fire was about one-third and statistically different ($p < 0.01$) from that of trees with high crown scorch or those that died quickly.

Discussion

Even though this study was relatively short, the impact of several factors was evaluated on the probability of short-term tree fall or, conversely, length of time standing after fire-caused mortality. Little research has dealt with fall rates or retention of fire-killed trees, especially following prescribed fires, which typically take place on sites where snags for wildlife habitat are important. Lyon (1984) studied lodgepole pine snag retention following a severe wildfire in which most trees were killed immediately with the passing fire. In the first 2 years after the fire, less than 2 percent of the snags fell. During the next 13 years, the average annual fall rate was about 13 percent, which is about 4 percent lower than the average annual fall rate in the current study. Raphael and Morrison (1987) calculated the probability of snag fall in a mixed conifer stand that had experienced a severe wildfire 15 years prior to their research. During a 5-year study, 55 to 65 percent of the dead Jeffery pine and lodgepole pine fell, and little difference in fall rate was noted for trees between 5 and 15 inches d.b.h. Unique to the current study are the examination of the impacts of different seasons of tree injury, different levels of injury, and the length of time between injury and death. These could have implications for snag creation and retention in managed stands.

With less mortality in the autumn treatment (fig. 1), fewer trees were available for falling, but percent tree fall differences were not statistically significant (fig. 2). Keen (1929) found that fall rates were similar for trees killed by bark beetles in the summer and the autumn. Lack of significant difference between the 62 percent autumn fall rate and the 78 percent spring and summer fall rate in the current study may be partially due to the small sample size in the autumn treatment, as only 21 trees died and 13 fell. However, an indication based on two findings shows that trees may stand longer if mortally wounded when dormant (autumn) compared to when actively growing. First, figure 4 and the associated analysis show that trees that died within the first year of injury had a higher probability of imminent falling than those that survived the first postfire year but died later. Second, 74 percent of the total tree mortality in the spring and summer burns occurred in the first postburn year compared to only 48 percent of the total from autumn fire injury. Therefore, the fact that severe injury in the spring and summer led to a greater chance of early mortality than that caused by autumn fires, implies that a lower probability of early falling for the autumn-killed trees has some credibility.

With greater mortality in the smaller size classes, more trees were available for falling, but tree fall rates were similar among size classes (fig. 3). Following a wildfire in lodgepole pine, Lyon (1984) reported that trees less than 3 inches d.b.h. had an average annual fall rate of 27 percent, while trees between 3 and 8 inches d.b.h. fell at about one-third that rate. Dahms (1949) found that about 75 percent of wildfire-killed ponderosa pine between 8 and 20 inches d.b.h. fell in the first 10 postfire years compared to 35 percent of the 20- to 30-inch trees and 15 percent of the 30- to 42-inch trees.

Greater surface area of decay-resistant heartwood for larger, presumably older trees likely explains these fall rate differences between size classes. In the current study, the ranges of d.b.h. and ages by size class may not have been different enough to expect dissimilar amounts of heartwood. Random tree aging indicated that many trees 3 to 5 inches d.b.h. were only 10 to 15 years younger than trees 12 to 15 inches d.b.h., which averaged 90 to 95 years old.

Results of this study indicate a possible relationship between level of crown scorch and length of survival after injury. In the first postburn year, 51 percent of the 10-year mortality occurred for low-scorched trees compared to 66 percent for high-scorched trees. By the third postburn year, 77 percent of the low-scorch trees' 10-year mortality was complete compared to 92 percent for high-scorched trees.

An assumption might be made that if crown scorch and length of postfire survival are related, then only one criterion is necessary to evaluate probability of early tree fall. Indeed, high scorch regardless of length of survival led to almost an 80 percent fall rate, and first-year mortality led to an equally high fall rate. However, even though trees that died following low scorch but survived at least 2 years postburn had only a 27 percent fall rate, low-scorched trees with first-year mortality fell at a 75 percent rate. This indicates the value of both characteristics. Also, based on a small sample size, of the seven high-scorched trees that died after the third postfire year, four (57 percent) fell before the end of the 10-year study, but of the eight low-scorched trees that died in that last 7 years, none fell.

Trees in most size and vigor categories can be blown down by high winds. But some structural decline generally has to be present for trees, live or dead, to fall under low to moderate winds. With the exception of trees having burned-out basal scars or heavy fuel consumption around the root crown, the structural integrity of most fire-injured trees is initially unchanged (Kimmey 1955). Other agents become involved in response to fire injury leading to structural deterioration, which increases tree fall potential.

Fire-damaged or fire-killed trees typically attract bark beetles and other insects (Miller and Keen 1960; Mitchell and Martin 1980) that can assure tree mortality by girdling the cambium or phloem. Insects that feed on sapwood and heartwood can reduce structural quality, making these trees somewhat more susceptible to falling (Kimmey 1955; Schmid and others 1985).

A primary activity associated with successful insect attacks is the introduction of fungi that occurs most often on insect bodies, but also by air-borne means (Lowell and others 1992). First to infest the sapwood generally are stain fungi that slow water transport within the tree but cause limited structural decline (Kimmey 1955). Decay fungi, which generally follow stain fungi, destroy wood cells. This results in reduced bole strength, thereby increasing the likelihood of tree fall (Keen 1955).

A tree's resistance to insect and disease attack is determined largely by the intensity of the attack and the tree's chemical defenses. The intensity of the insect attack is generally related to the severity of the damage, with greater injury resulting in greater attacks (Miller and Keen 1960; Ryan 1993). However, trees with fire-consumed crowns and extensive bark charring do not normally attract bark beetles. The capability of the chemical defense mechanism is determined largely by tree vigor (Kaufmann and Stevens 1984; Matson and others 1987) and, perhaps, phenological state (Lorio 1986).

Conifers respond to pest attacks primarily by synthesis and translocation of resin that can physically flush out or isolate attackers and may contain toxic monoterpenes (Berryman 1972; Lieutier and Berryman 1988; Raffa and Berryman 1982). The synthesis and movement of large quantities of resin and monoterpenes are energy demanding (Raffa and Berryman 1982, 1983). Waring and Pitman (1985) reported that allocation of carbohydrates for chemical defense likely has the lowest priority, occurring only after production for foliage, buds, roots, stem elongation, and storage reserves. Because the amount of photosynthate determines the amount of carbohydrates allocated for each function, reducing crown volume by scorching would have a great impact on resources for defensive action (Gerry 1931; Harper 1944).

Injured trees with low vigor as well as those with high vigor are capable of at least initiating resinosis of infected tissue (Owen and others 1987; Raffa and Berryman 1982). Therefore, even if the injured tree dies, some resin movement has likely occurred. Because resin delays fungal spread and, therefore, cell deterioration, higher resin concentrations and larger resin-soaked areas would greatly retard stem decay and probably lengthen the time a tree would stand after death.

In this study, trees that died with low crown scorch but survived for 2 or 3 years after injury had only a 27 percent probability of falling within the 10-year study. This compares with greater than 75 percent probability of falling for those with low scorch and first-year mortality, and those with high scorch regardless of years of survival after injury.

Insect attacks were noted on all dead trees, but the intensity of the attack was not estimated. With 80 percent or greater crown scorch and, therefore, high loss of photosynthetic tissue, the high probability of early falling was likely due to the limited ability to produce quantities of resins sufficient to resist insect invasion and stem decay. With low crown scorch but first-year mortality, early falling may have resulted from minimal resinosis due to initial low tree vigor, limited response time, or massive insect attacks, that can overwhelm even healthy trees (Raffa and Berryman 1982). The lower probability of falling for trees with low scorch and 2 or 3 years of postinjury survival may have been the result of sufficient resin synthesis from the higher volume of residual photosynthetic tissue and sufficient time for resin translocation to a large area of the stem. Therefore, wood decay before and after mortality would be retarded.

Management Implications

If stand and prescribed burn conditions resemble those of this study, low mortality could be expected. Of the trees that die, a relatively high fall rate could be anticipated within 10 years of fire injury. When managers are evaluating tree mortality from the viewpoint of potentially enhanced wildlife values or added woody debris, they should expect that 75 to 80 percent of the trees that die in the first postburn year will fall within 10 years.

Trees that have an extended wildlife value, especially for nesting and perching, will be those with moderate crown scorch and that remain alive for 2 years or more after injury. Mortally injured trees with these characteristics will not be distinguishable in an immediate postburn evaluation. A survey during the second or third postburn year will allow better determination of long-term snag presence in the stand.

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Fall rates of prescribed fire-killed ponderosa pine were evaluated relative to tree and fire damage characteristics. High crown scorch and short survival time after fire injury were factors leading to a high probability of early tree fall. The role of chemical defense mechanisms is discussed. Results apply to prescribed-fire injured, second-growth ponderosa pine less than 16 inches diameter at breast height.

Keywords: snags, crown scorch, tree fall, chemical defenses

INTERMOUNTAIN RESEARCH STATION

The Intermountain Research Station provides scientific knowledge and technology to improve management, protection, and use of the forests and rangelands of the Intermountain West. Research is designed to meet the needs of National Forest managers, Federal and State agencies, industry, academic institutions, public and private organizations, and individuals. Results of research are made available through publications, symposia, workshops, training sessions, and personal contacts.

The Intermountain Research Station territory includes Montana, Idaho, Utah, Nevada, and western Wyoming. Eighty-five percent of the lands in the Station area, about 231 million acres, are classified as forest or rangeland. They include grasslands, deserts, shrublands, alpine areas, and forests. They provide fiber for forest industries, minerals and fossil fuels for energy and industrial development, water for domestic and industrial consumption, forage for livestock and wildlife, and recreation opportunities for millions of visitors.

Several Station units conduct research in additional western States, or have missions that are national or international in scope.

Station laboratories are located in:

Boise, Idaho

Bozeman, Montana (in cooperation with Montana State University)

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