

# Deterioration of fire-killed trees in the Rocky Mountain Region



United States  
Department of  
Agriculture

Renewable Resources  
Technical Report  
R2-RR-11-01

Forest Service  
Denver, Colorado



# Deterioration of Fire-Killed Trees in the Rocky Mountain Region

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**Abstract:** We assessed deterioration of 851 fire-killed trees over six years following the wildfires of summer 2002 (sampling in 2002-2007). Five tree species and nine wildfires were studied in seven national forests of the Rocky Mountain Region. One year after the fires, subalpine fir had lost about 40% of volume to fire-related defects and Engelmann spruce about 20%; loss in other species was negligible. The early loss was due primarily to checking, as suggested by the steep declines in log density due to rapid drying of wood and the absence of sap rot after one year. After two years, volume loss of subalpine fir and Engelmann spruce was about 60%. That of ponderosa pine was highly variable, about 10% in two southern fires but over 60% in fires in the Black Hills. Sap rot became an increasing component of defect during this time. Wood borer galleries continued to increase through the fourth year. Sapwood stain (not considered a defect) was only abundant in lodgepole and ponderosa pines, where it reached a maximum in two years. Although data on internal, pre-existing decay (heart rot) were variable, evidence suggests it did not expand significantly in the dead trees. By three years after the fires, all species on all fires were substantially affected and volume losses averaged over 50%. Nineteen species of wood-boring insects were identified from emergence traps. Thirty-eight species of fungi decaying the trees were identified from cultures, including one new record for Colorado, but these represent a small portion of the decay community in these trees.

**Key words:** Wildfire, tree deterioration, decomposition, wood decay, borers, fungi.

Following the unprecedented 2002 fire season in the Rocky Mountain Region (Anonymous 2003), there was demand from Forest Service and timber industry representatives for information on the rate and type of deterioration of fire-killed trees. Most of this interest was related to marketability and salvage of timber, but there was also interest in the hazard of trees in developed areas as well as the ecological processes of decay and deterioration of the coarse woody debris.

A literature search showed that there was information for some of our tree species, but it was highly variable and almost all from other regions. Therefore, we initiated a project to gather the needed information and began implementation in fall of 2002 within months of the fires. The goal was to provide answers to these questions that will be useful after future fires.

Martinez DL, Ryszka G, Worrall JJ, Mask RA, Eager T, Egeland L. 2011. Deterioration of Fire-Killed Trees in the Rocky Mountain Region. USDA Forest Service, Rocky Mountain Region, Renewable Resources, Technical Report R2-RR-11-01. 36 pp.

## 1. LITERATURE REVIEW

### 1.1 Snag longevity

Although we did not measure fall rates of snags in this study, it is often of interest following a large-scale mortality event, so we review some relevant studies here. Studies of snag longevity following bark beetle outbreaks and fires are included.

**Ponderosa pine.** One of the largest and longest studies of snag longevity was by Keen (1955). In the northern Sierra Nevada, various surveys marked and numbered beetle-killed snags of ponderosa pine annually from 1919 to 1949. The rate of fall was very low for the first five years (at the end of which 85% were still standing), very rapid between 5 and 15 yr, then tapered off to a very low rate. After 25 years, 10% of snags were still standing. Small trees with high proportion of sapwood fell faster than the average. Loam soils had a more rapid fall rate than the drier pumice soils of the area. Kimmey (1955) noted that many ponderosa pine killed by fire break off at ground level or up to 50 ft high during the 4<sup>th</sup> and 5<sup>th</sup> year.

Beetle-killed ponderosa pine ranging from 7-22" DBH was studied in the Front Range of Colorado (Schmid *et al.* 1985). No trees fell within two years of death. Thereafter, an annual fall rate of 3-4% was observed, but the rate soon increased to as high as 17%. When winds exceeded 75 mph, more snags fell. On one site, 70% of trees were down within six years, but for other sites this took ten years. 90-100% of trees fell to the east, further supporting the role of strong winds in many fall events. Most trees broke between the soil line and two feet above. Beetle-killed ponderosa pine snags fell more quickly on the Black Hills National Forest in South Dakota (Schmid *et al.*, 2009). Only one of 277 monitored snags broke within two years, but after five years, 76%, 91% and 95% of snags were broken in three stands. The most common point of failure was in the first two feet above ground, but nearly 25% broke at 25-35 feet high.

Seven years after wildfire in northern Arizona, 41% of ponderosa pine snags had fallen (Chambers & Mast 2005). In a chronosequence of severe fires in northern Arizona (Passovoy & Fulé 2006), fallen snags increased with time. In fires 3-4 yr old, 14.6% of snags were down, but that increased to 60.8% in fires 8-9 yr old.

Ponderosa pine was followed up to 11 yr after two wildfires in western Idaho (Russell *et al.* 2006). Snag dynamics were similar in the two fires; 55-60% of snags were down after 9 yr and 85% were down after 11 yr. Estimated half-life (50% of snags down) was 7-8 yr in salvage-logged plots and 9-10 yr in unlogged plots. The logging effect was due largely to a reduction in average snag size (smaller snags fall sooner) and partly to a reduction in density.

Ponderosa pine killed by an escaped, prescribed fire was studied in west-central Oregon (Dahms 1949). Snags were first tallied 10 yr after the fire and they were followed for 12 additional years. Ten years after the fire about 55% of the snags were down. At the end of the study, at 22 yr, 78% were down. The curve was nearly flat, with very low fall rate, by that point. Smaller snags tended to fall early. Unlike Douglas-fir, which reportedly tend to gradually break down from the top, the pine snags tended to fall by uprooting.

Ponderosa pine killed by prescribed fire was also studied by Harrington (1996), on the San Juan National Forest. Fall rates were higher than in the California and Oregon studies. Five years after death, up to 50% of trees were down (in the spring/summer burn treatment). Nine years after death, 62-78% of trees were down. There was not a significant difference in fall rate among tree sizes, but all trees were small, probably accounting for the unusually high fall rates.

On the east side of the Cascades in Washington, Everett *et al.* (1999) studied a chronosequence of fires and estimated that small ponderosa pine snags (<23 cm DBH) had a half-life of only about 7 yr. Too few larger ponderosa pine snags were available for regression analysis, but it appeared they lasted longer.

**Lodgepole pine.** Lodgepole pine killed by fire was studied in Montana (Lyon 1977). Very few snags fell in the first two years. Thereafter, snags  $> 3''$  DBH fell at  $8.4\% \text{ yr}^{-1}$ . Ten years after the fire, the percentage of snags down was: 3–8'', 47%; and 8–12'', 62%. There was high variability among transects. Slope and snag density did not influence fall rate.

Hinds *et al.* (1965) included some lodgepole pine in a study of beetle-killed spruce in Colorado. Trees averaged 12'' DBH and fell at an average annual rate under  $2\% \text{ yr}^{-1}$  for 17 yr. It was estimated that 45% of the stems would be down in 20 yr.

In the study by Everett *et al.* (1999; see ponderosa pine above), small lodgepole pine snags ( $< 23$  cm DBH) had a half-life of only about 11 yr and medium snags (23–41 cm) about 15 yr. No large snags were available for study.

In dry sites in central Oregon, 602 previously tagged trees were monitored annually after a mountain pine beetle outbreak (Mitchell & Preisler 1998). Some plots had been thinned from below before the outbreak, and suffered lower mortality (20%) than the unthinned plots (43%). Snags began falling 3–5 years after death. Half were down in 8–9 yr, and 90% were down in 12–14 yr. Snags in thinned stands fell slightly faster than those in unthinned stands. After a lag phase, annual fall rates were about 10% per year in unthinned plots and 13% in thinned plots (these authors apparently calculated their fall rates each year on the basis of the original number of trees, rather than the number remaining the year before). Small trees fell slightly faster than large trees in thinned stands, but not in unthinned stands. These are among the fastest falling snags of all the studies reviewed here.

In northeastern Oregon, Harvey (1986) also measured fall rate of beetle-killed lodgepole pine. Of 427 trees, only one fell in the first 5 yr. By 10 yr, however, 25% had fallen.

In British Columbia, stands resulting from a 1979 outbreak of mountain pine beetle were assessed 25 years later (Anonymous 2007). Among 14 plots, the snags still standing (divided by those plus the ones on the ground) ranged from 0 to 80%, with an average of approximately 45%.

A more recent study in British Columbia investigated a chronosequence of lodgepole pine killed by mountain pine beetle (Lewis & Thompson 2009). Snag fall was negligible until 6 yr after mortality, and most rapid beginning at 8 yr. Fall rate was highly variable among plots. Snag failure was due primarily to sap rot near the soil line. DBH had no significant relationship to fall rate.

**Spruce.** Engelmann spruce snags killed by spruce beetle were studied in Utah (Mielke 1950) and in Colorado (Hinds *et al.* 1965). They fell much more slowly than the pines already reviewed. In the Dixie National Forest, Utah, snags were tallied 25 yr after the outbreak. Only 16% of the snags appeared to have fallen during that period. Fall rate was not influenced by aspect, slope, or soil type. Annual fall rates were 0.92% for snags 3–7'' DBH and 0.69% for those  $> 8''$ . Decay in the roots and/or butt was considered the primary factor in causing 77% of snags to fall.

In the Colorado study, snag fall (termed “windthrow”) was reported on the basis of volume. One would expect that to be lower than a tree basis since fall rate is generally lower in larger size classes, but the authors reported that the percentage fall rate was essentially similar by the two bases. About 8% were down 10 yr after peak mortality, and 28% after 20 yr. This was much higher than in the Utah study, apparently because of the high incidence of root and butt rot in the trees when they were killed. Decay at the base, including butt rot, was thought to substantially contribute to fall of 96% of the snags.

In the eastside Cascades study of Everett *et al.* (1999), Engelmann spruce snags had an exponential decay curve that varied by size. They estimated that medium-sized snags (23–41 cm DBH) had a half-life of about 23 yr, while larger snags had a half-life of 20 yr. However, the curve for large snags flattened later, so it was estimated that after 80 yr, up to 30% of large spruce snags would remain standing, while the medium class would retain only 15–20% for that period.

Norway spruce logs on the ground in Norway were studied to determine date of death by cross-dating ring chronologies of the fallen log (Storaunet & Rolstad 2002). This study was not based on

a single mortality event or cause. Date of fall was determined either by dating wounds inflicted during the fall on neighboring trees, or by aging trees that had established on the fallen log. The frequency of time from death to fall had a reverse J-shaped distribution, with a mean of 22 yr and a range of 0-91 yr. Decomposition was more closely related to time since fall than to time since death.

**Douglas-fir.** Russell *et al.* (2006) included Douglas-fir in their study (see above under ponderosa pine). Snags fell at a lower rate than for ponderosa pine. There appeared to be some discrepancy in actual fall data between the text and a figure, but 10% or 18% of snags fell in 9 yr in the unlogged area, and 15% or 19% fell in the partly salvage-logged area in 11 yr. Estimated half-life of snags was 15-16 yr in unlogged plots and 12-13 yr in salvage-logged plots, which is difficult to reconcile with either of the sets of actual data.

In the chronosequence of fires on the east side of the Cascades (Everett *et al.* 1999), small Douglas-fir snags (<23 cm DBH) had a half-life of only 9-10 yr and were gone by 45 yr. Medium snags (23-41 cm) were 50% gone in about 15 yr. However, larger snags had a half-life of about 35 yr, and after 80 yr 40% still remained standing. These large Douglas-fir were the most persistent snags of the study, which included five species.

**Subalpine fir.** Subalpine fir fall rates were studied by decay class in British Columbia (Huggard 1999). Trees were grouped into decay classes so that fall rates could be based on features recognizable by forest workers. Range of time since death for each class was determined by cross-dating increment cores. Fall rate was estimated by the number of snags and ages of the class, assuming that the same number of trees become snags each year. Annual fall rate increased with decay class (*Table 1*). Calculations suggest that 20% of snags fall by 27 years and 50% by 53 years. Because the fall rate of the first snag class was not higher than that of live trees (*Table 1*), Huggard recommended that they be disregarded as hazards to forest workers, and that they not be felled unless they have obvious structural defects.

*Table 1.* Annual fall rates of subalpine fir in British Columbia by class (Huggard 1999).

Class	Time since death (yr)	Annual fall rate (%) ± standard error
Live trees		0.5 ±0.1
Fine branches present, bark intact	0-19	0.2 ±0.9
Fine branches few, bark cracked	12-35+	0.7 ±0.9
Fine branches none, ≤50% bark lost	16-66+	3.7 ±0.9
Fine branches none, >50% bark lost	40-90	6.0 ±1.7

In the east Cascades chronosequence of fires (Everett *et al.* 1999), small subalpine fir (<23 cm DBH) had a half-life of about 11 yr. Medium snags had a half-life about 25 yr. Insufficient large snags were available for regression.

**Summary of snag longevity.** It is difficult to directly compare studies. In part this is because of varying ranges of tree size, which influences fall rate. Also some reports provide results as percentages of fallen snags at particular times and some give annual fall rates. Further, authors do not always clarify whether their calculated annual fall rate is based on number of trees at the time of the original mortality event, or at the beginning of each year. It is important to note that the curve relating percent of snags remaining (or fallen) is not straight when the annual fall rate is constant. Figure 1 illustrates some representative annual fall rates on a standard graph.

Tree size is a major factor in nearly all studies: fall rate is inversely related to size. Where snag density was considered, studies vary in concluding whether there is a significant effect on snag longevity.

Few studies made direct comparisons among species in snag fall rates. Everett *et al.* (1999) found that, with trees <41 cm DBH, the thin-barked species Engelmann spruce, subalpine fir and

lodgepole pine lasted longer than the thick-barked species Douglas-fir and ponderosa pine. In larger size classes, however, Douglas fir persisted longer than spruce.

The effect of cause of tree death on snag fall rate is frequently discussed. On this subject, Keen (1955) wrote,

*“Foresters sometimes believe that snags resulting from fires stand longer than those arising from insect kill, reasoning that insects carry in wood rots, whereas fire-killed snags are often ‘case-hardened’ and sterilized. Dahms has reported the rate of fall for fire-killed snags on pumice soils at Pringle Falls Experimental Forest: About 50 percent were standing at the end of 10 years, and 25% at the end of 18 years. This rate is similar to that for beetle-killed snags on the pumice soils [in this study]. Although the cause of death may have an influence on rate of fall, it would appear that soil conditions are more important.”*

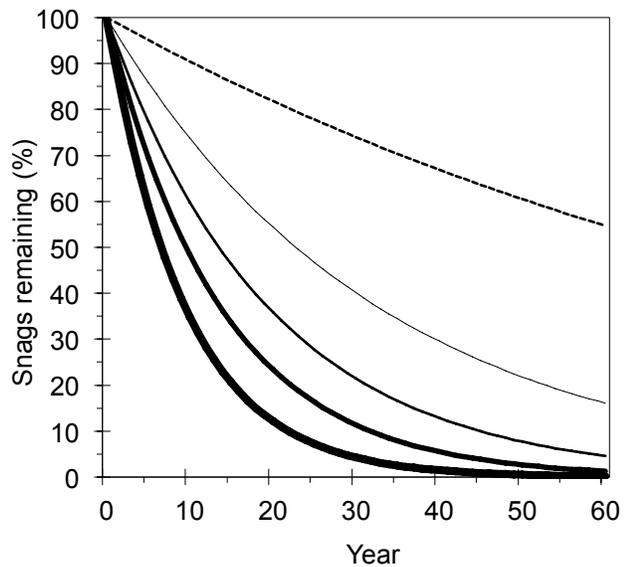


Figure 1. Hypothetical curves of constant annual rates of snag fall. From the top curve, the rates are 1, 3, 5, 7, and 10% per year. Annual fall rate as used here is the number of snags that fall each year, expressed as a percentage of the number standing at the beginning of the year. In reality, there is usually a lag of several or more years before a constant rate is reached, and the rate may not remain constant over time.

## 1.2 Deterioration of beetle- and fire-killed trees

Lowell *et al.* (1992) comprehensively reviewed the literature on deterioration of fire-killed trees up to 1990. That review emphasizes information on reduction in product value that is not covered here. DeNitto *et al.* (2000) supplemented that with a brief additional review before focusing on summarizing the 5-year study of Hadfield & Magelssen, which at that time was only available from annual reports, but has since been published comprehensively (Hadfield & Magelssen 2006). The current review is based on the original literature.

Perhaps the first comprehensive, large-scale deterioration study in the U. S. considered fire-killed Douglas-fir in western Oregon and Washington (Kimmey and Furniss 1943). Volume losses in cubic and board-foot terms are summarized in Figure 2. In the first year, blue stain and ambrosia beetles developed in the sapwood. By the end of year 2 (young trees) or year 4 (old trees), decay and wood borers obscured the stain and ambrosia beetle galleries throughout the sapwood. Certain borers and decay fungi then progressed into the heartwood. Their rate of progress was unabated or even increased in young trees, but in old trees the heartwood often remained mostly sound until about 15 years, when the rate of movement increased. However, large trees lost less volume than small trees in large part because it takes fungi and borers longer to penetrate to the same proportion of the radius. The basal log was the slowest to decay, presumably because of the high moisture content (inadequate oxygen). Decay rate was correlated with growth rate of the wood (ring width). The two most important decay fungi were *Fomitopsis pinicola* (overall 59% of decay volume, decaying both sapwood and heartwood) and *Trichaptum abietinum* (30%, sapwood only). Wood borers sometimes caused significant damage to sapwood and heartwood. Weather checking was minimal, except for the tops of trees on dry sites.

*Fomitopsis pinicola* was an important decay fungus leading to basal failure in beetle-killed ponderosa pine in the Black Hills National Forest, South Dakota (Schmid *et al.*, 2009). Where

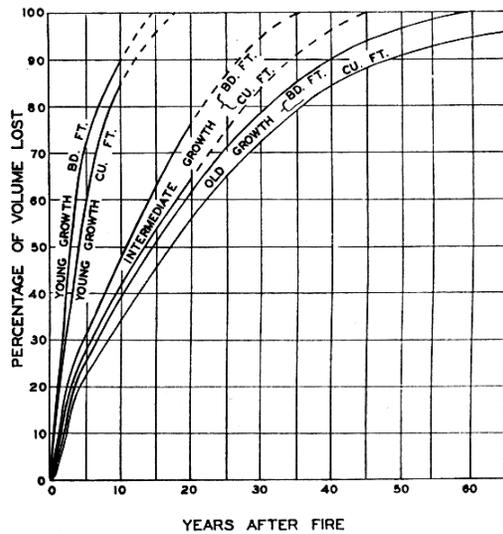


Figure 2. Average progress of board-foot and cubic-foot volume loss in fire-killed Douglas-fir for the modal DBH class of three growth types (young 21-30" intermediate 41-50", old 51-60"). Broken lines indicate extrapolation beyond the age of burns studied for young and intermediate types. Figure 13 of Kimmey & Furniss (1943).

which has the most decay-resistant heartwood and thinnest sapwood; it deteriorated at about the same rate as found by Kimmey & Furniss (1943). Large Douglas-fir still had heartwood <35% decayed after 17 years. However, small trees, <26" DBH, were over 50% cull after only two years because of the high proportion of sapwood. Sugar pine and ponderosa/Jeffrey pine (latter two species combined) were intermediate. Insects were considered important in creating entry points for fungi, but few were important directly in economic deterioration. The most important decay fungus in all species was *Fomitopsis pinicola*, followed by *Trichaptum abietinum*. *Cryptoporus volvatus* was also blamed, but subsequent workers noted that, although this fungus fruits early and abundantly, it often does so before there is any evidence of decay in the sapwood, it seems to grow most heavily in bark, and it decays the sapwood only superficially and then is replaced by other decay fungi (Boyce 1961; Gilbertson & Ryvardeen; Hadfield & Magelssen 1996, 1997).

Douglas-fir killed by a variety of causes was studied in interior British Columbia (Thomas & Craig 1958). Time of death was determined by cross-dating annual rings, and live trees were also sampled to quantify stem decay at the time of death and follow it through deterioration. Heart rot<sup>1</sup> apparently developed little following tree death: live trees had 3.9% volume loss (cubic-foot basis) from heart rot and dead had 4.3%. Volume losses were extremely erratic over time, especially beyond six years when only a few sample trees were available for each time point. In contrast to Kimmey & Furniss (1943), these authors found greater rates of volume loss in large than in small trees. Dry conditions apparently led to rapid desiccation and thus low decay of small trees. Also in contrast to the earlier study, and probably also because of drier conditions, volume loss to decay was greatest in the bottom log and least in the top log. Over all dead trees and times studied, sap rot loss averaged 12.4%. The same two fungi as found by Kimmey & Furniss (1943) caused the over-

breakage was common at 25-35 ft high, it appeared that *Cryptoporus volvatus* may have been an important decayer.

Another interesting trend documented by Kimmey & Furniss (1943) is that damage to heartwood by wood borers (but not decay) is correlated with nearness to previous fires. This suggests that populations of insects may be limiting unless a nearby fire has facilitated population increase. *Arhopalus (Criocephalus) productus*, a roundheaded borer, was the chief insect causing damage to the heartwood.

Five conifer species killed by fire were studied in California by Kimmey (1955). After one year, the only loss was usually degrade of sapwood caused largely by blue stain. After the second year, most of the sapwood and even some heartwood was cull. After the third year the rate of loss slowed as only heartwood remained undegraded. White fir deteriorated the fastest, 10-20% of cubic volume after one year. One year later, 50% was decayed, resulting in cull of about 70% of the board-foot volume. At the opposite extreme was Douglas-fir,

<sup>1</sup> The terms "saprot" and "heartrot" (or sap rot and heart rot) are commonly used but rarely defined in the literature. Thomas & Craig (1958) explicitly defined sap rot as "rot established following tree mortality" and heartrot as "rot established prior to tree mortality." These definitions are compatible with most uses of the terms. In general, heartrot primarily occurs in (but is not restricted to) the inner wood, while sap rot begins in the outer sapwood and progresses inward.

whelming majority of sap rot, *F. pinicola* (83%) and *T. abietinum* (12%). Heart-rot volume loss, which was lower (4.3% of gross cubic volume), was caused primarily by *Phaeolus schweinitzii* (44%), *Porodaedalea (Fomes) pini* (25%), and *Antrodia carbonica* (19%). Average volume loss was greater in trees and logs with high numbers of bark beetle galleries than in those with lower numbers.

Fire-killed trees of five species were measured for defect for three years after wildfires in southern Oregon and northern California (Lowell & Cahill 1996). Preexisting defects were ignored. Almost the only significant defect in the first year was radial checking (weather checking), resulting in 1-5% loss. The second and especially the third year, sap rot was strongly dominant, contributing to 8-10% loss in year 2 and 26-37% loss in year 3.

Beetle-killed Engelmann spruce in Colorado was followed up to 20 years after the period of peak mortality in some areas (Hinds *et al.* 1965). After 20 years, about 40% of the original cubic volume had been lost: 2/3 of the loss was due to falling of snags (see 1.1) and 1/3 was due to decay in residual standing snags. Decay losses leveled off at about 12% 12 to 15 yr after tree death, apparently due to drying of the wood. Butt rots and trunk rots, which were already active before death, were included in the estimates. Some appeared to continue decaying after death, but sap rots dominated increasingly with time since death.

Residual standing, beetle-killed Engelmann spruce, examined 25 yr after the period of peak mortality on the Dixie N.F., Utah, were considered to be sound except for sap rot within several feet of the ground (Mielke 1950). Moisture contents of spruce wood generally fell below a level that can support decay within three years. Checking was the only significant defect, but it appeared to progress to a certain degree and then stop. Blue stain was present, but was pale and did not affect value of the wood. Few of the trees were attacked by wood borers; they were mainly confined to the bases of large trees. Ambrosia beetles were noted in some trees, but were confined to the narrow sapwood and so were removed with slabs in the mill.

Deterioration in three tree species was studied 29 months after fire on Vancouver Island, British Columbia (Wallis *et al.* 1971). Douglas-fir had an average of 3.6 insect galleries ft<sup>-2</sup>, primarily ambrosia beetles and cerambycids. Decay occupied 12% of the wood volume and increased strongly with height in the tree. Decay fungi isolated were *Stereum sanguinolentum*, *Amylostereum chailletii*, and *Fomitopsis pinicola*. Western hemlock had 2.2 insect galleries ft<sup>-2</sup> but differed from Douglas-fir in that siricids dominated, followed closely by ambrosia beetles. Decay occupied 24% of wood volume, again increasing with height. Decay fungi were *A. chailletii*, *Heterobasidion annosum*, and *F. pinicola*. Western red cedar had much less insect activity than the other species, only 0.7 galleries ft<sup>-2</sup>. Decay was nearly absent.

Beetle-killed Douglas-fir also deteriorated rapidly in western Oregon and Washington (Wright & Wright 1954). Percentage cubic-foot (and board foot) losses to decay were about 10% (19%) after two years, 19% (32%) after four years, and 28% (44%) after seven years. Sapwood deterioration was generally so advanced after two years that it was not usable for lumber. Heartwood began to deteriorate within four years, and by eight years there was usually no commercial value, even for pulp. Volume losses from decay were faster in the smaller trees because of the greater proportion of sapwood. *Cryptoporus volvatus* fruited frequently by one year after mortality, and *Fomitopsis pinicola* began to appear at two years.

Beetle-killed Douglas fir was later revisited in Oregon, along with grand fir, but in the eastern part of the state, which is considerably drier than the west (Parry *et al.* 1996). Accordingly, rates of increase in sap rot were lower, even though there was a greater proportion of sapwood than in the earlier study. After three years, disk measurements indicated that Douglas-fir had 8.1% loss of cubic volume to decay, compared to about 15% in the western study. After four years, it was 11.4% in the east and 19% in the west. Sap rot in grand fir was lower, 8% after four years. In scaling, losses were higher: cubic volume deductions for Douglas-fir after three years were 23% for cull

logs, 4% for pre-existing defect, 27% for sap rot, and 4% for weather check. Sap rot was more advanced toward the butt, while weather check was more important toward the top.

Lodgepole pine was included in the beetle-kill study by Hinds et al. (1965) described above. There were no detectable changes in decay in lodgepole pine over the course of the study. Decay was dominated by trunk rots; sap rots were very minor.

Following widespread fires in eastern Washington in 1994, a large-scale, 5-year deterioration study was initiated (Hadfield & Magelssen 2006). Seven tree species were included in five wildfires, with four plots for most species and five plots for two species. Each year for five years, beginning the year after the fires, five trees were cut in each plot. Cubic volume lost to cracks (checks) was calculated by subtracting from the cylinder wood from the cambium to the average crack depth, even when there were only one or two cracks. This may overestimate volume loss in many cases, depending on the number, distribution and spiral nature of the cracks. By this measure, cracks were the largest cause of volume loss (*Figure 3*). Decay was a significant source of loss only in the thick-barked species: ponderosa pine, grand fir, and Douglas-fir. Char was an insignificant cause of volume loss, affecting less than 0.1% of wood volume. Wood borers were noted after one year and generally increased for the first few years. Percentage of discs with borer holes in the year the maximum was recorded, by species in descending order, were western larch (94), Douglas-fir (83), ponderosa pine (74), grand fir (65), Engelmann spruce (28), subalpine fir (16), and lodgepole pine (12). Drying of wood apparently limited borer activity in many cases.

Western larch killed by a 2001 fire in northwestern Montana has been followed for five years in what is planned as a 10-year study (Jackson 2006). After five years, checks generally penetrated an average of 3.2-3.6", regardless of tree size, with an average of 1-2 checks at any point. This was most of the radius of small trees and a minor portion of large trees. Borers generally penetrated about half to two-thirds of that depth. Sap rot occupied an average of 14 to 20% of cubic volume, depending on size class. Trees were grouped into four size classes. Among the three largest classes, proportion of volume decayed decreased as size class increased. However, the smallest size class had the lowest proportion of volume decayed. This may have been due to drying of the smaller trees. In some cases, sap rot had begun to penetrate the heartwood by the end of the fifth year.

### 1.2.1 Decomposition of downed logs

Decomposition of logs of several species was studied in Minnesota (Alban & Pastor 1993). The trees had been felled live, bucked, and left for 14-17 years, so this is a much different situation than the studies of standing snags above. All species lost half or more of wood density during the study. Aspen and white spruce decayed most quickly; red pine was intermediate, and jack pine was decayed most slowly.

Decomposition of windthrown Engelmann spruce and lodgepole pine was studied in the Fraser Experimental Forest, Colorado (Brown *et al.* 1998). Cross-dating of annual rings was used to determine time since death, which ranged up to about 140 years. Density decrease of lodgepole pine from 0-140 yr was imperceptible (slope =  $-0.0004$ ,  $R^2 = 0.08$ ) and for spruce from 0-75 yr it was slow (slope =  $-0.0015$ ,  $R^2 = 0.38$ ). However, fraction remaining of estimated original volume decreased more rapidly.

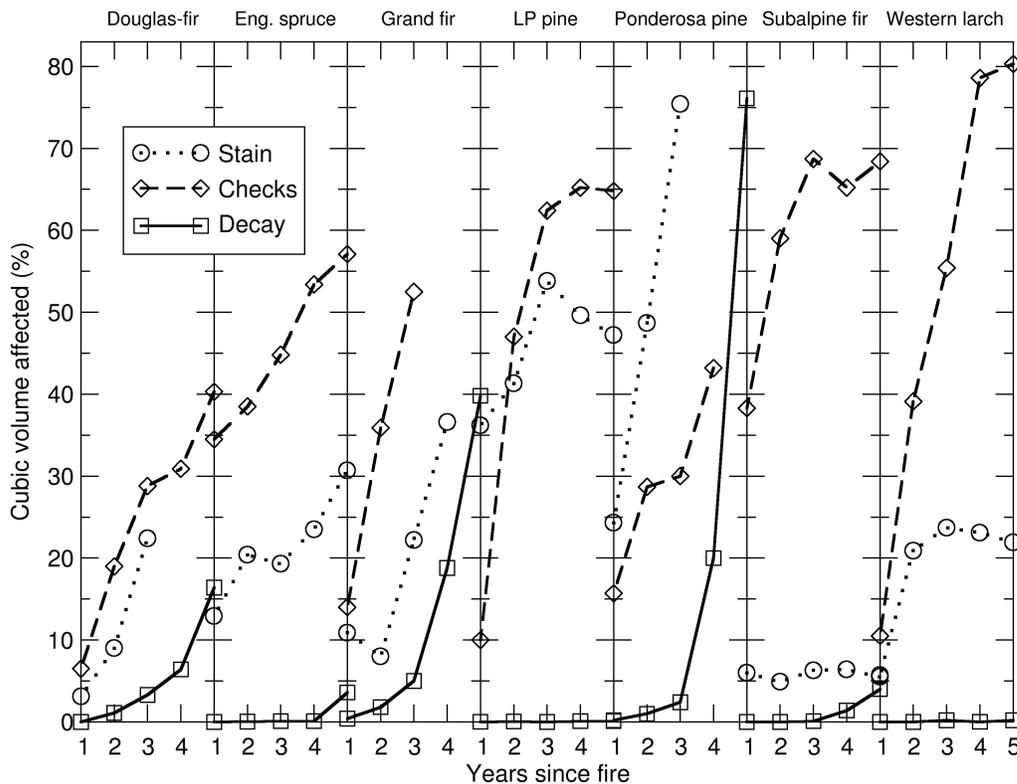


Figure 3. Average volume affected by stain, checks (cracks) and decay from one to five years after wildfire in eastern Washington. Where stain and check curves are truncated, they became obscured by decay and could not be calculated. Based on data of Hadfield & Magelssen (2006)

### 1.2.2 Summary of deterioration of fire- and beetle-killed trees

Generally, blue stain (sap stain) appears during the first year and often increases for several years thereafter. It is considered “limited deterioration,” possibly affecting the value of the wood, but generally not the usable volume. Pines generally show the most intense blue stain, and because some of them have thick sapwood, the effect can be significant. Sap stain is generally obliterated by sap rot a few years later.

Similarly, wood borers generally begin to appear in the first year and increase for several subsequent years. Borers appear in heartwood later and may continue to affect deeper wood for 5-6 years. Most workers consider borers to also be limited deterioration. However, where the only market is lumber and boreholes are unusually abundant, volume may be lost.

Weather checking is the radial splitting that occurs as stems dry below the fiber saturation point, as wood shrinks. It is highly variable and depends mostly on climate (humidity, temperature and wind), bark thickness, and diameter. It can appear in the first year and usually reaches a maximum after 3-4 years. If decay is able to proceed, many checks become obscure over time. In dry climates, thin-barked species and small trees, weather checking may be the dominant cause of volume loss in the first several years after a fire.

Sap rot is decay that generally begins after death in the outer wood. It often appears in the second year, and may occupy 50% of the sapwood by then. Decay continues to progress until the tree is consumed or desiccates. In species with thin sapwood and under good moisture conditions, sapwood may be almost all decayed by the end of the third year. Decay progresses toward the

center, but may slow when the heartwood is reached. As decay progresses inward, progressively smaller volumes are affected for a given depth of penetration.

Literature on deterioration of lodgepole pine was reviewed by Lewis & Hartley (2006), including more references than covered here. They concluded that generally, in the regions of interest (primarily British Columbia), decay and insects were not substantial defects. This is because trees tended to fall (due to decay largely limited to the ground line) before those factors affected significant volume. Instead, reduced moisture content, checking and blue stain were the most important factors in deterioration. Trees with loose bark had some losses but were still merchantable. This is generally consistent with the information on lodgepole pine reviewed above.

As pointed out by Lowell et al. (1992), many of the major early studies dealt with large trees in old-growth stands. Most trees cut today are considerably smaller. Thus, deterioration is probably faster today than suggested by the early studies.

*Table 2.* Some important factors that influence deterioration rates of dead trees and the nature of the influence.

Factor	Influence	Comments
Moisture	There is an optimum moisture content of wood for biological deterioration, with inhibition at both ends of the spectrum. Decay stops and weather checking (radial splits) begins when wood dries below the fiber saturation point (~28% moisture content on dry weight basis).	West-wide, conditions range from too dry to too wet in terms of the optimum for biological deterioration. When wood is too wet, there is inadequate O <sub>2</sub> for decay, when too dry, fungi are inactive. Weather-checking may be the primary, early cause of loss on dry sites and on small trees, but is often negligible on wet sites and large trees.
Tree species	Species vary in deterioration rate.	Variation is primarily due to differences in heartwood durability, bark thickness, and sapwood thickness. Some species have little or no heartwood durability (e.g., white fir) while others are moderately durable (Douglas-fir).
Sapwood thickness	Thicker sapwood increases deterioration rate and volume loss.	After a tree dies, sapwood is defenseless and fully susceptible to stain, decay and insect invasion.
Bark thickness	Varies depending on climate.	Bark thickness primarily influences moisture content and drying rate. In dry climates, thick-barked tree parts dry slowly, allowing biological deterioration to continue. In wet climates, thick-barked parts may remain too wet for much deterioration.
Growth rate	Wood with narrow rings generally decays slowly, especially in heartwood.	Slow-growing wood generally has high lignin content and high proportion of latewood, which slow fungi and insects.
Tree size	Larger trees generally deteriorate slowly, though this may be reversed in dry conditions because small trees dry out too quickly for early biological deterioration.	Larger trees deteriorate slowly because they often have a greater proportion of heartwood, and growth rings are often narrow (see Growth rate). Also, the difference is a simple result of geometry: if deterioration progresses inward a certain depth in a given period, the wood lost is a higher percentage of volume in small trees than in big trees.
Position in tree	Varies with climate.	In wet conditions, deterioration is often greatest in upper portions of the tree. In dry conditions, tops often dry too fast and biological deterioration is faster toward the bottom of the stem. Weather checking is usually greatest toward the top.
Fire severity	Bark damage speeds bark shedding, influencing moisture content. Severely damaged bark is not colonized by bark beetles and most wood borers.	On dry sites, more severely burned trees may lose bark and dry faster than less severely burned trees. Also, borers cannot establish. Reduced rate of deterioration results.

Many factors influence deterioration rates (*Table 2*). The two most important factors are probably moisture and tree species. These are especially important when considering commercial timber species and value loss.

Accurate recognition of early stages of wood decay is difficult. Field detection of decay relies on discoloration (stain) representing the first visual evidence, fiber pulling from earlywood in saw cuts, softening of early wood, and more obvious features of advanced decay. However, substantial strength is lost in the early stages of decay, often well before its presence is readily apparent (Zabel & Morrell 1992). Decay may be missed by scalers, but becomes obvious in the mill when the wood is sawn or dried. On the other hand, even if decay is present and deducted by scalers, the mill may choose to ignore it (Lowell *et al.* 1992).

## 2. METHODS

### 2.1 Study design

The study was designed to sample five trees in each plot every year for six years: the year of the fires (fall of 2002) through the fifth year after the fires (2007). Thirty trees of a single species comprised a plot. Fires and plot locations were chosen to represent the five major tree species in the Region (*Table 3*).

*Table 3.* Tree species and codes used as abbreviations.

Species	Common name	Code
<i>Abies bifolia</i>	Rocky Mountain subalpine fir	ABBI3
<i>Picea engelmannii</i>	Engelmann spruce	PIEN
<i>Pinus contorta</i> var. <i>latifolia</i>	lodgepole pine	PICO
<i>Pinus ponderosa</i> var. <i>scopulorum</i>	Rocky Mountain ponderosa pine	PIPO
<i>Pseudotsuga menziesii</i> var. <i>glauca</i>	Rocky Mountain Douglas-fir	PSME

Each species was represented in five plots on two fires on different national forests, except that Douglas-fir was sampled on only one fire, and ponderosa pine was sampled in nine plots on four fires on three national forests (*Table 4, Figure 4*). Lodgepole pine was not sampled in 2002, but was added in 2003.

*Table 4.* Fires in the study, showing location and number of plots by tree species and fire.

Fire	Approx.						Forest	Ranger District	
	burn date	2002	ABBI3	PICO	PIEN	PIPO			PSME
Big Fish	Aug. 19	3			4		White River	Blanco	
West Beaver	June 26	2			1		Uncompahgre	Norwood	
Bucktail	May 15					3	Uncompahgre	Norwood	
Million	June 21					2	Rio Grande	Divide	
Hayman	June 10						5	Pike	South Park
Battle Creek	Aug. 19					2	Black Hills	Hell Canyon	
Grizzly Gulch	July 2					2	Black Hills	Northern Hills	
Bear Mtn. South	July 14		3				Medicine Bow	Brush Ck./Hayden	
Pass Creek	Aug. 29		2				Shoshone	Washakie	

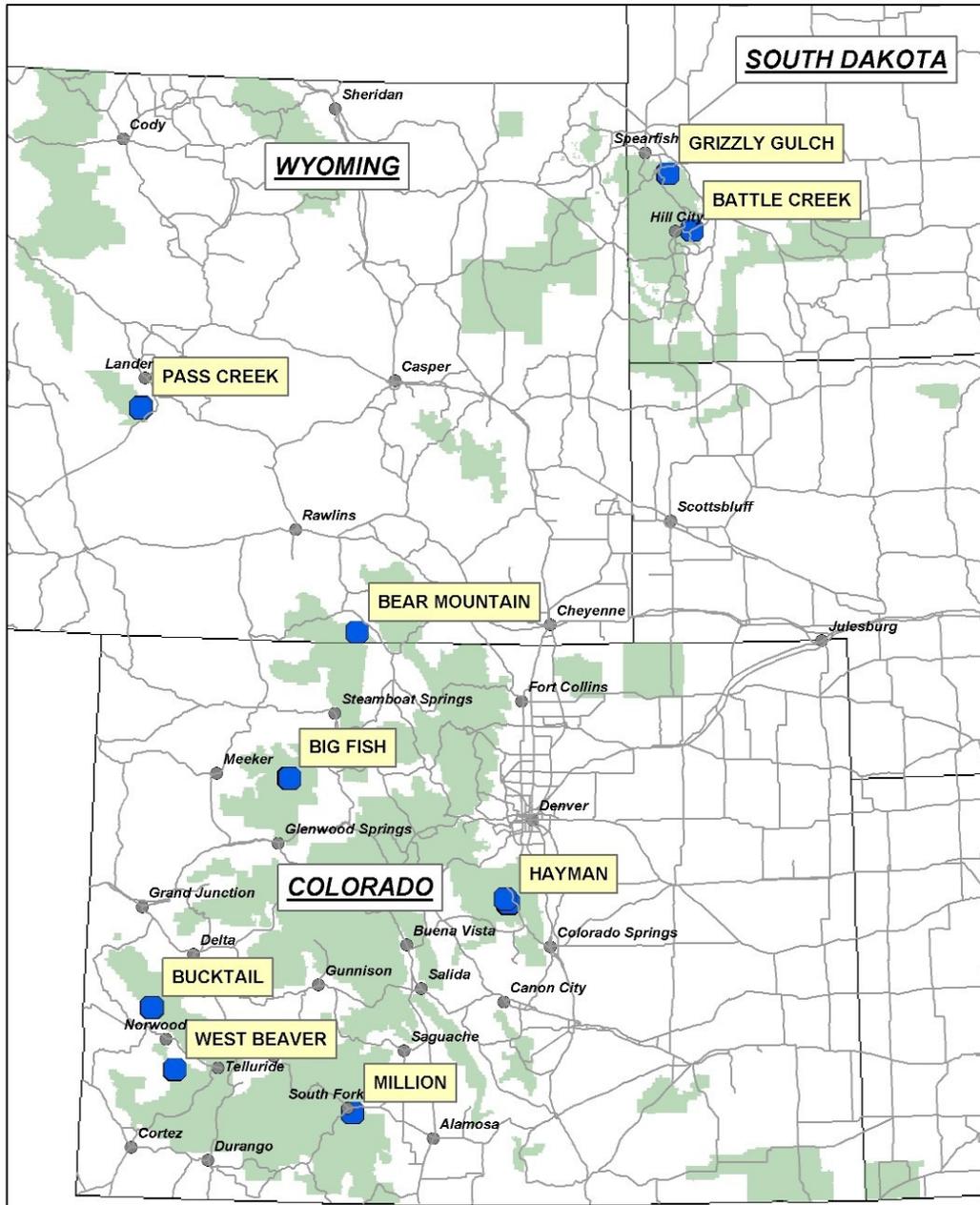


Figure 4. Locations of fires sampled in the study.

## 2.2 Field methods

The 30 trees in each plot were chosen in the first year of sampling. Criteria for inclusion were merchantable size (minimum 8.0" DBH and at least 16' to a 6" diameter top inside bark) and no more than 20% of crown still green. Otherwise the only bias in selection was to ensure a representative range of tree sizes. Trees were marked and tagged and the following data were recorded:

1. DBH
2. Burn severity by following scale:
  - a) Light: needles not burnt to less than half burnt
  - b) Moderate: more than half foliage consumed but fine twigs remain

- c) Severe: most fine twigs consumed.
  - d) Extreme: no fine twigs left and considerable larger branches consumed.
3. Bark scorching, recorded as percent of basal circumference and maximum height apparently scorched, based on external appearance.
  4. Evidence of pre-fire cracks and other defects.

Each year, 5 trees were randomly selected among the remaining trees in each plot. Occasionally, the selected tree could not be found or had fallen to the ground. Missing trees had presumably been cut for firewood, but may also have fallen and been lost in the tangle of debris and undergrowth. In such cases new standing trees were selected. The selected trees were felled and marked for log lengths prior to bucking.

Log lengths for each tree were determined by applying the segmentation rules found in Forest Service Cubic Scaling Handbook, FSH 2409.11a. A maximum log length of 20 feet was used. Logs were measured from the one foot stump to 6.0 inches diameter inside bark on the small end. For example: a log measuring 32.8 feet to the 6.0 inch top was scaled and recorded as two 16 foot segments with trim allowance. A log measuring 43 feet was scaled as three 14 foot segments with trim allowance. Smalian's formula was used to calculate gross cubic volume.

Scaling rules and defect deductions were applied to the log segments in the determination of gross and net quantity of timber products. Rules from the Cubic Scaling Handbook, FSH2409.11a, were used in assessing defects affecting production of boards or veneer. Mean scaling defect of each species, by fire, was determined over the six years of sampling. Defect was separated into those resulting from fire and fire mortality (e.g., weather check, sap rot) versus pre-existing defects (e.g., sweep, crook, butt rot). A minimum diameter inside of bark (DIB) of 6.0 inches and a merchantability factor of 10.67 was utilized in the determination of cubic volume.

Log density (pounds per cubic foot, including moisture) was calculated for each tree by utilizing the small chunk procedure for arriving at cubic foot weight factors found in chapter 80 of the Timber Cruising Handbook, FSH 2409.12. The procedure involved taking chunks of wood approximately the same length from DBH, and top of each log segment in each tree (Figure 5). The chunks were measured to arrive at a cubic volume, and then weighed. The sum of weight and volume was totaled for each tree then the average density was calculated for the population by species and study.

To estimate stand ages, in the first three sampling years (2002-2004) trees were aged by counting rings at the stump wherever this could be done reliably in the field. In cases of butt rot or other problems that prevented aging at the stump, the tree was aged at a higher point and the height from ground was recorded. In a few cases, disks were brought back to the laboratory for aging.

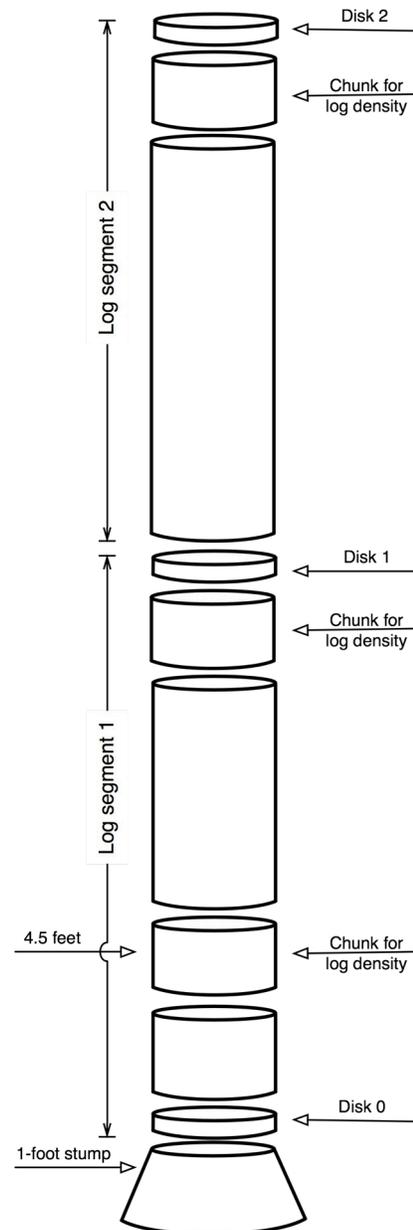


Figure 5. Locations of samples within trees relative to log position. Any additional log segments were sampled as for log 2. Not to scale.

At each log end, insect activity in wood was estimated. Bark was removed for 1 x 0.5 feet on opposite sides of the log (1 ft<sup>2</sup> total). The presence of any galleries and insects in the cambium area was noted, and holes into the wood and live insects were counted by the following categories: ambrosia beetles, cerambycids (roundheaded borers), buprestids (flatheaded borers), and siricids (woodwasps).

A disk was cut from each log end for estimation of decay and stain, and for wood density sampling. The following data were recorded for each disk:

1. mean diameter inside bark
2. mean diameter of internal decay (heart rot)
3. mean depth and percentage of circumference with outer decay (sap rot)
4. mean depth and percentage of circumference with blue stain
5. mean depth and percentage of circumference with char (wood burnt)

We intended to measure deterioration separately in sapwood vs. heartwood, but in most cases they were not clearly distinguishable, so we did not record the difference consistently.

For determination of dry wood density, as a measure of decomposition over the time series, six samples were taken from each disk. The disk was first split in a random direction. When sapwood and heartwood were clearly distinguishable, three 1" x 1" blocks were taken, evenly spaced, from sapwood and three more from heartwood. Otherwise, blocks were evenly spaced from the cambium to the pith.

Any wood-boring insects or wood-decay fungi that were noted on fire-killed trees (or in the case of adult insects, flying in the plot) were collected for identification. In addition, emergence traps were placed on adjacent non-plot, mature, fire-killed trees, and specimens emerging over the previous year were removed annually during plot measurement. Emergence traps consisted of window screen fastened over the outer bark. The traps were removed, and the specimens collected for later laboratory identification. Traps were replaced on these "emergence trees" for the following year's collection.

## **2.3 Laboratory methods**

### **2.3.1 Dry wood density (specific gravity)**

Wood density measurements were conducted generally as described by Harmon & Sexton (1996). Volume of blocks was measured preferentially by weight of water displaced. Blocks were first submerged in water until water absorption was insignificant over the course of several minutes. A beaker of water was placed on a balance and tared. A block was placed on a needle and suspended in the water. The increase in weight (grams) due to water displacement was recorded as the block volume in cm<sup>3</sup>.

If the sample had insect galleries, advanced decay, or other voids associated with deterioration, water would penetrate those voids rather than being displaced, misrepresenting the sound volume. In such cases, the volume was instead measured with a micrometer. Each dimension was measured at the four corners and averaged before calculating volume. In cases of very advanced decay, where the wood did not retain its shape, the volume was estimated roughly from amount of sample and the sizes of the other blocks from the disk. Blocks were then dried at 103 C (217 F) to constant weight. Density was calculated as dry weight (g) divided by volume (cm<sup>3</sup>).

### 2.3.2 Fungal isolations

During 2006 only, in order to isolate and identify decay fungi, additional sample blocks were taken from disks with decay (internal or sap rot). Blocks were kept frozen in the laboratory until isolation. Isolations were made onto a benomyl-dichloran medium (Worrall 1991). Blocks were split often to expose a fresh surface for isolation. Generally four plates were used per sample block, with four chips per plate. Any fungi with morphological characteristics of wood-decaying hymenomycetes were transferred to MEA.

For identification, we had a small number of voucher cultures from identified fruiting bodies to use in comparative identification. However, the primary method was using published keys and descriptions of cultures of wood-decay fungi (Ginns & Lefebvre 1998, Nobles 1958, 1964; Stalpers 1978; Wang & Zabel 1990). Enzyme tests described in those references were also used.

### 2.4 Data analysis

Gross cubic volume of each log was calculated using Smalian's formula:  $\left(\frac{A_1 + A_2}{2}\right)L$ , where  $A_1$  and  $A_2$  are the cross-sectional areas of wood (inside bark) at each end of the log, and  $L$  is the log length.

Tree volume was determined by summing the volumes of the logs. Volume of stain or decay was determined similarly: the areas of defect recorded on the disks at each log end were summed, divided by two, and the result multiplied by log length.

## 3. RESULTS

In 2002, within months of the fires, we sampled 24 plots. In 2003, the year after the fires, through 2007, we sampled 29 plots, having added lodgepole pine to the study. Over the six years of sampling, 851 trees were felled and assessed. This is six more trees than expected because occasionally extra trees were cut.

The plots with the oldest trees were in the West Beaver (spruce and fir) and Hayman (Douglas-fir) fires (*Table 5*). The West Beaver fire also had some of the largest trees in the study, including spruce and fir, with merchantable height as tall as 97 feet. Most of the ponderosa pine plots and some of the spruce and fir plots on the Big Fish fire were relatively young, around 100 yr. These included ponderosa pine on the Bucktail and Million fires, but those plots had some of the larger trees in the study. Lodgepole pine trees in all plots were almost all of relatively small diameter.

### 3.1 Defect

The most prevalent fire-related defects affecting lumber and veneer production in this study included heart checks, weather checks, voids, sap rot, insect damage and breakage. Fire-killed trees tend to have more felling breakage than green trees due to lack of cushioning from foliage and undergrowth and brittleness of the dry wood. Stain affects only grade of wood products and was not considered in defect determination.

By year three all five species in all fires had lost over 40% of merchantable cubic volume due to fire-related defect and all but one ponderosa pine plot had lost over 50% (*Figure 6*).

### 3.2 Log density

All species showed a progressive decrease in mean log density (pounds per cubic foot) from year to year with the exception of ponderosa pine in the Battle Creek and Grizzly Gulch study areas

between 2006 and 2007 (*Figure 7*). During this period, mean pounds per cubic foot results in these two study areas increased by 13.43% and 10.19% respectively. This increase is most likely due to replacement trees being selected for all samples in the Battle Creek and Grizzly Gulch areas during 2007. All designated samples for 2007 had either fallen down or were missing in these two fire study areas. However, it may also reflect increased moisture content due to environmental conditions.

Interestingly, when comparing different study areas, average log density by species were virtually the same by 2007 (*Figure 7, Table 6*). This is true despite initial mean weights by species varying considerably among study areas.

*Table 5.* Mean ages and diameters of trees by species, fire and plot. Ages are based on ring counts of stems in first three sampling years. Only trees aged at 2.0 feet or less above ground are included.

Species	Fire	Plot	Mean age (yr) $\pm$ standard deviation			Mean diameter (in.) $\pm$ standard deviation		
			Plot	Fire	Species	Plot	Fire	Species
ABBI3	Big Fish	2	148 $\pm$ 36			10.8 $\pm$ 1.7		
		4	131 $\pm$ 56			11.8 $\pm$ 3.2		
		6	97 $\pm$ 22	121 $\pm$ 45		11.5 $\pm$ 2.9	11.4 $\pm$ 2.8	
	West Beaver	9	191 $\pm$ 32			14.7 $\pm$ 2.7		
		10	126 $\pm$ 8	158 $\pm$ 40	135 $\pm$ 46	13.5 $\pm$ 1.5	14.1 $\pm$ 2.3	12.4 $\pm$ 2.9
PICO	Bear Mtn. South	26	118 $\pm$ 12			8.9 $\pm$ 1.5		
		27	113 $\pm$ 11			10.0 $\pm$ 1.4		
		28	112 $\pm$ 7	114 $\pm$ 10		10.7 $\pm$ 2.2	9.9 $\pm$ 1.8	
	Pass Creek	29	104 $\pm$ 18			9.6 $\pm$ 1.0		
		30	137 $\pm$ 8	121 $\pm$ 21	117 $\pm$ 16	9.6 $\pm$ 0.8	9.6 $\pm$ 0.9	9.8 $\pm$ 1.5
PIEN	Big Fish	1	92 $\pm$ 33			10.9 $\pm$ 2.6		
		3	99 $\pm$ 32			13.4 $\pm$ 2.2		
		5	109 $\pm$ 30			11.5 $\pm$ 1.8		
		7	111 $\pm$ 42	103 $\pm$ 35		10.7 $\pm$ 2.2	11.6 $\pm$ 2.4	
	West Beaver	8	176 $\pm$ 44	176 $\pm$ 44	117 $\pm$ 47	17.1 $\pm$ 3.5	17.1 $\pm$ 3.5	12.6 $\pm$ 3.4
PIPO	Bucktail	11	94 $\pm$ 20			14.6 $\pm$ 2.9		
		12	103 $\pm$ 22			14.8 $\pm$ 2.6		
		13	103 $\pm$ 37	100 $\pm$ 27		13.9 $\pm$ 1.7	14.5 $\pm$ 2.4	
	Million	14	110 $\pm$ 15			14.3 $\pm$ 2.2		
		15	108 $\pm$ 15	109 $\pm$ 15		13.0 $\pm$ 2.5	13.7 $\pm$ 2.4	
	Battle Creek	21	98 $\pm$ 47			11.1 $\pm$ 2.1		
		22	86 $\pm$ 6	92 $\pm$ 32		9.8 $\pm$ 1.4	10.4 $\pm$ 1.9	
	Grizzly Gulch	23	127 $\pm$ 8			11.2 $\pm$ 2.2		
24		120 $\pm$ 8	123 $\pm$ 9	105 $\pm$ 25	11.0 $\pm$ 1.8	11.1 $\pm$ 2.0	12.6 $\pm$ 2.8	
PSME	Hayman	16	127 $\pm$ 8			13.2 $\pm$ 2.7		
		17	201 $\pm$ 21			13.7 $\pm$ 3.0		
		18	205 $\pm$ 62			12.5 $\pm$ 1.8		
		19	131 $\pm$ 23			12.3 $\pm$ 2.4		
		20	162 $\pm$ 57	165 $\pm$ 52	165 $\pm$ 52	11.8 $\pm$ 2.7	12.7 $\pm$ 2.5	12.7 $\pm$ 2.5

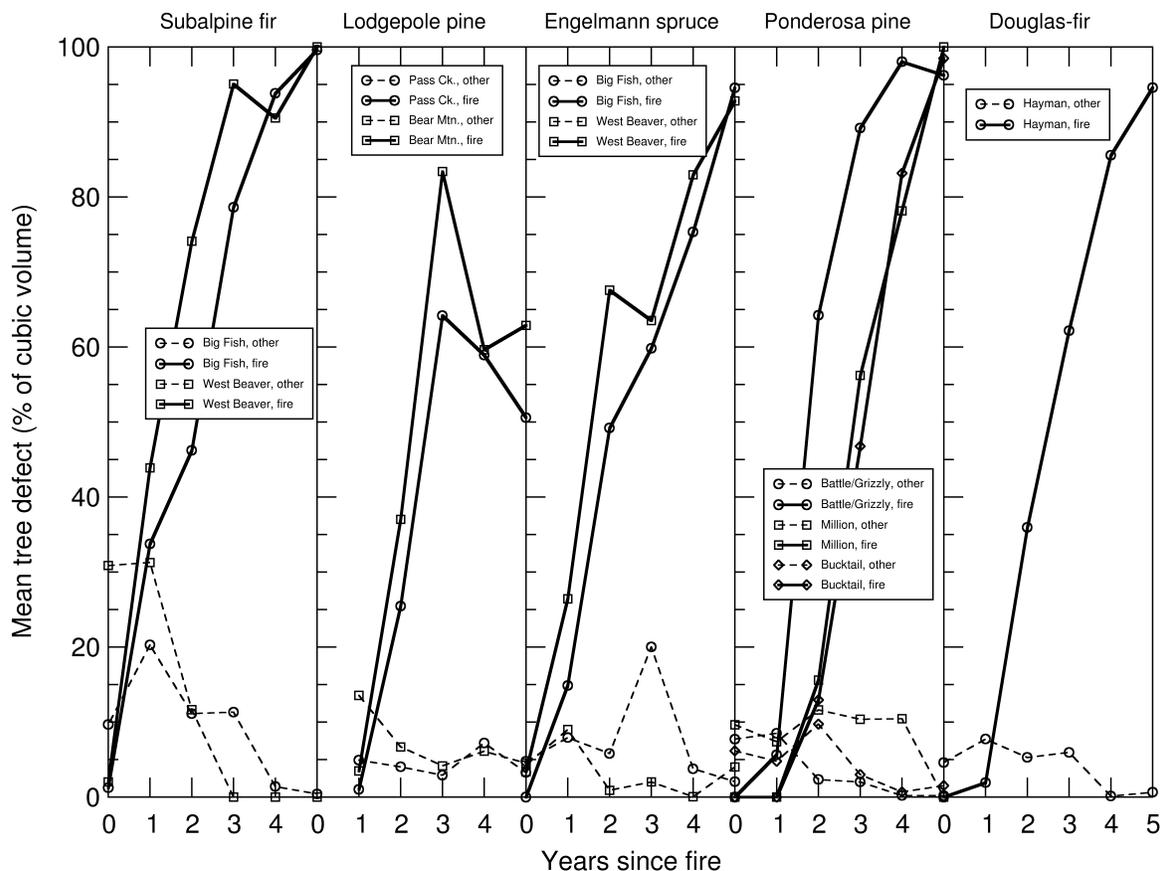


Figure 6. Mean scaling defect of each species, by fire, over the six years of sampling. Defect is separated into those resulting from fire and fire mortality vs. other, pre-existing defects. Cubic volume is total wood volume up to minimum merchantable diameter of 6 inches inside bark.

Table 6. Mean log density by species and fire.

Species	Fire	Log Density (lb/ft <sup>3</sup> )	
		Initial	Final
ABBI3	Big Fish	48.41	24.39
	West Beaver	34.59	23.44
PICO	Bear Mtn. South	41.71 <sup>a</sup>	29.61
	Pass Creek	41.71 <sup>a</sup>	29.31
PIEN	Big Fish	50.25	25.07
	West Beaver	37.45	24.95
PIPO	Bucktail	68.25	31.40
	Million	62.62	32.91
	Battle Creek	63.60	30.13 <sup>b</sup>
	Grizzly Gulch	53.59	33.15 <sup>b</sup>
PSME	Hayman	49.57	35.81

<sup>a</sup> Initial weights for PICO in Bear Mountain and Pass Creek were obtained from Riley Point Timber Sale, Bighorn N.F.

<sup>b</sup> Used 2006 data for Battle Creek and Grizzly Gulch for final density in this table because trees measured in 2007 were all replacements.

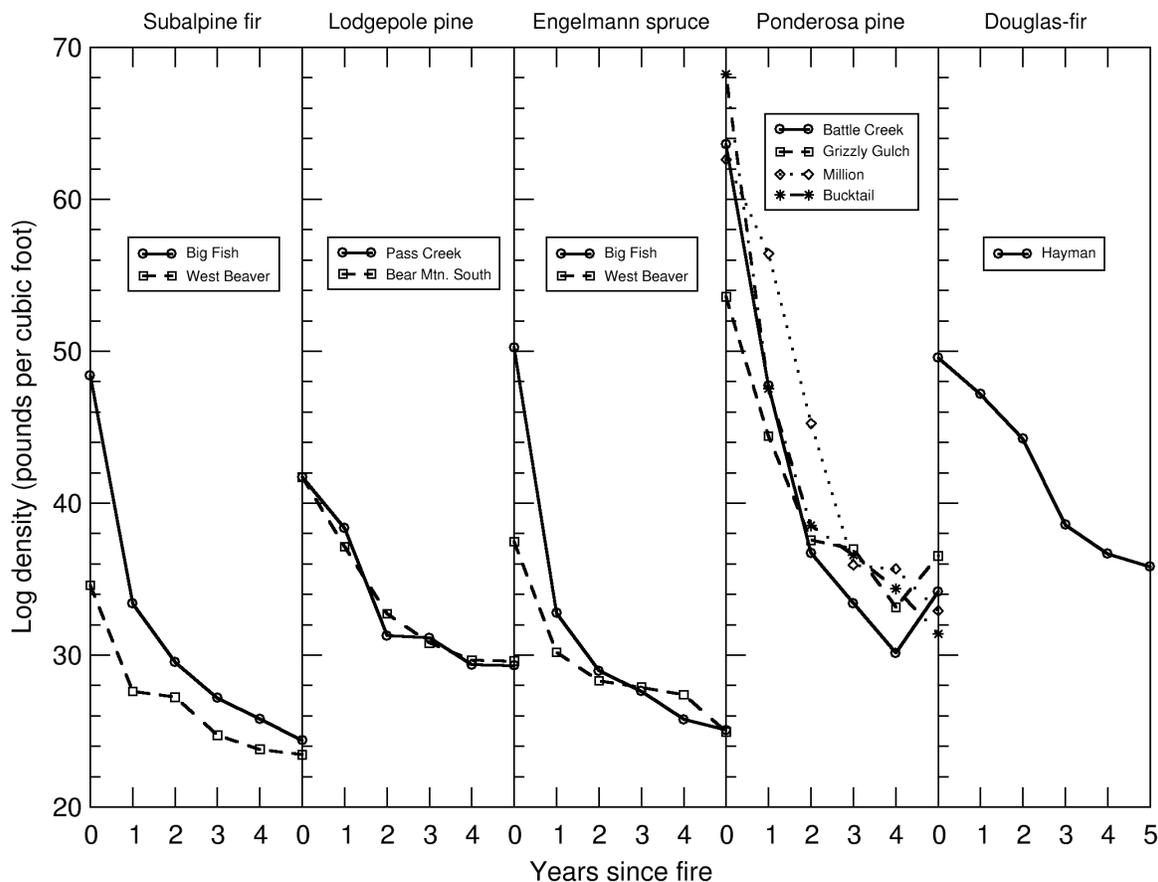


Figure 7. Mean log density of trees over time, by species and fire, as determined by field measurements.

### 3.3 Insects

#### 3.3.1 Insect damage

Numbers of borers generally increased up to four years after the fires (Figure 8). Boreholes continued to increase in Douglas-fir to the fifth year, while in subalpine fir there was no evidence of new attacks after the third year. Crew members had difficulty distinguishing among types of borers, based on the galleries, so cerambycids, buprestids and siricids were combined. Examination of the 2007 data, organized by disk position (Figure 9), showed that Engelmann spruce and subalpine fir had a clear trend of increasing borer density with height in the tree. Ambrosia beetle numbers were somewhat more erratic (Figure 10). They were generally most abundant in Engelmann spruce.

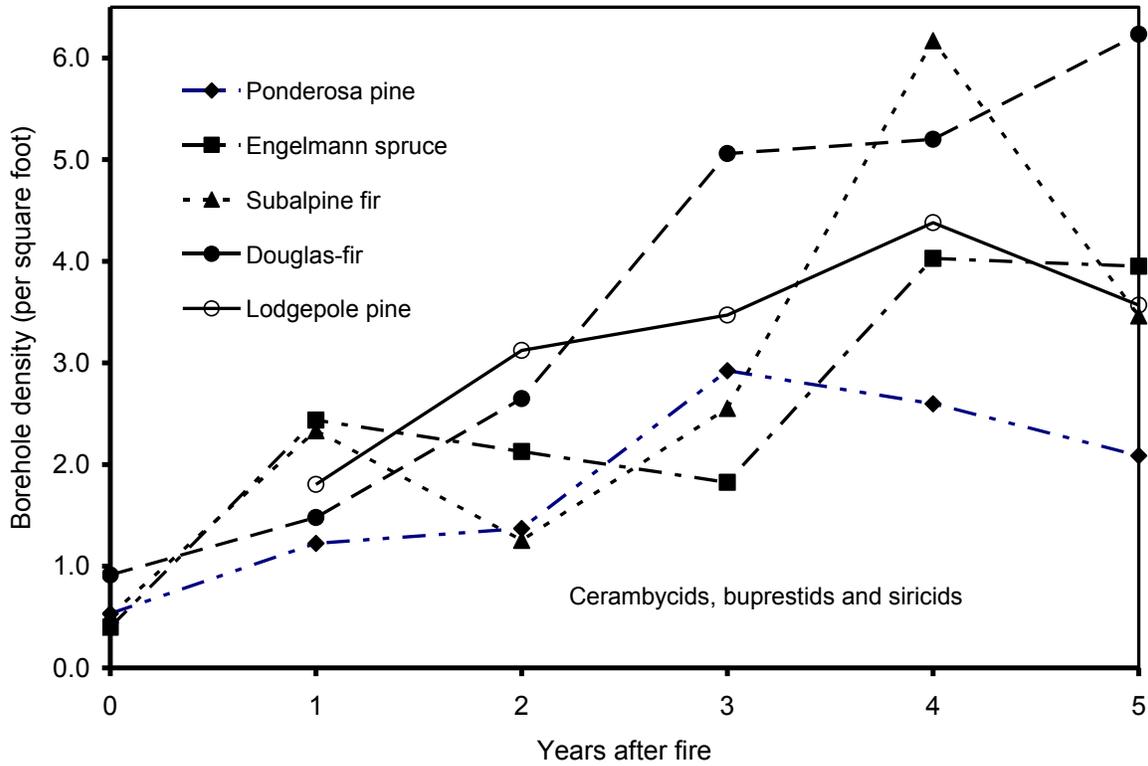


Figure 8. Density of wood borer holes (cerambycids, buprestids, and siricids combined) from 2002-2007.

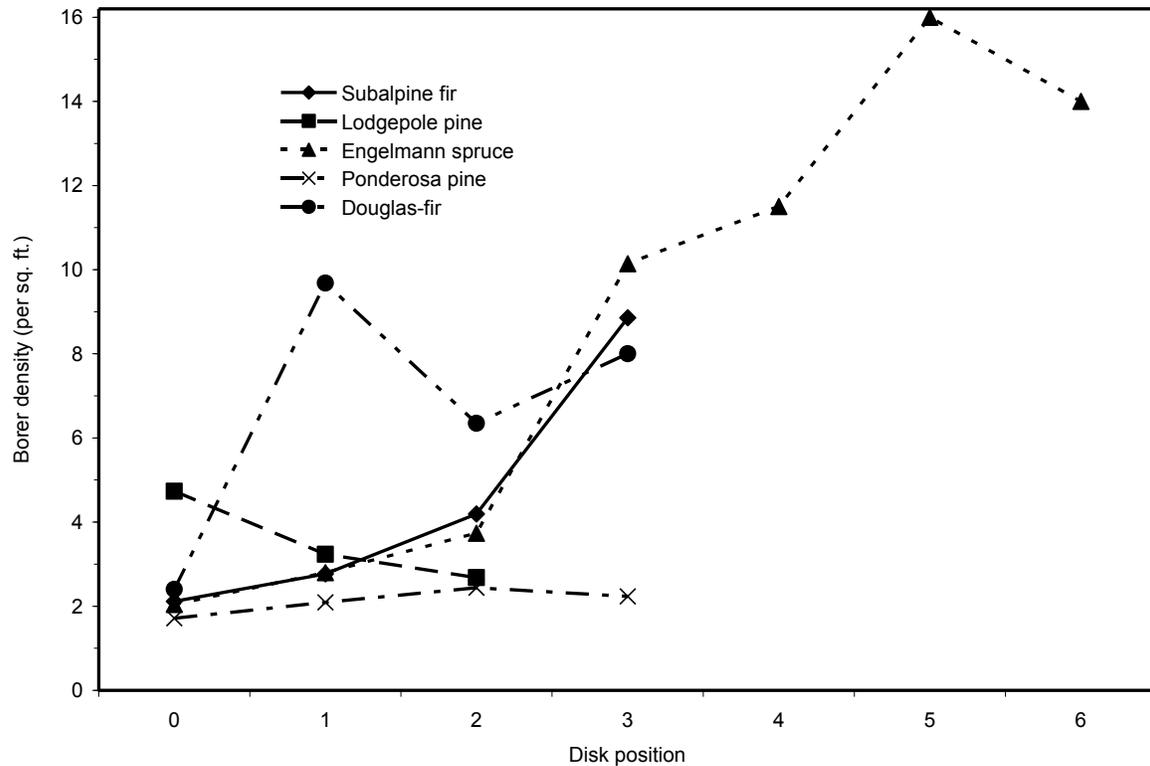


Figure 9. Borer density in trees sampled in 2007, by disk position. Includes cerambycids, buprestids and siricids. Note that progressively fewer trees are included at higher disk positions.

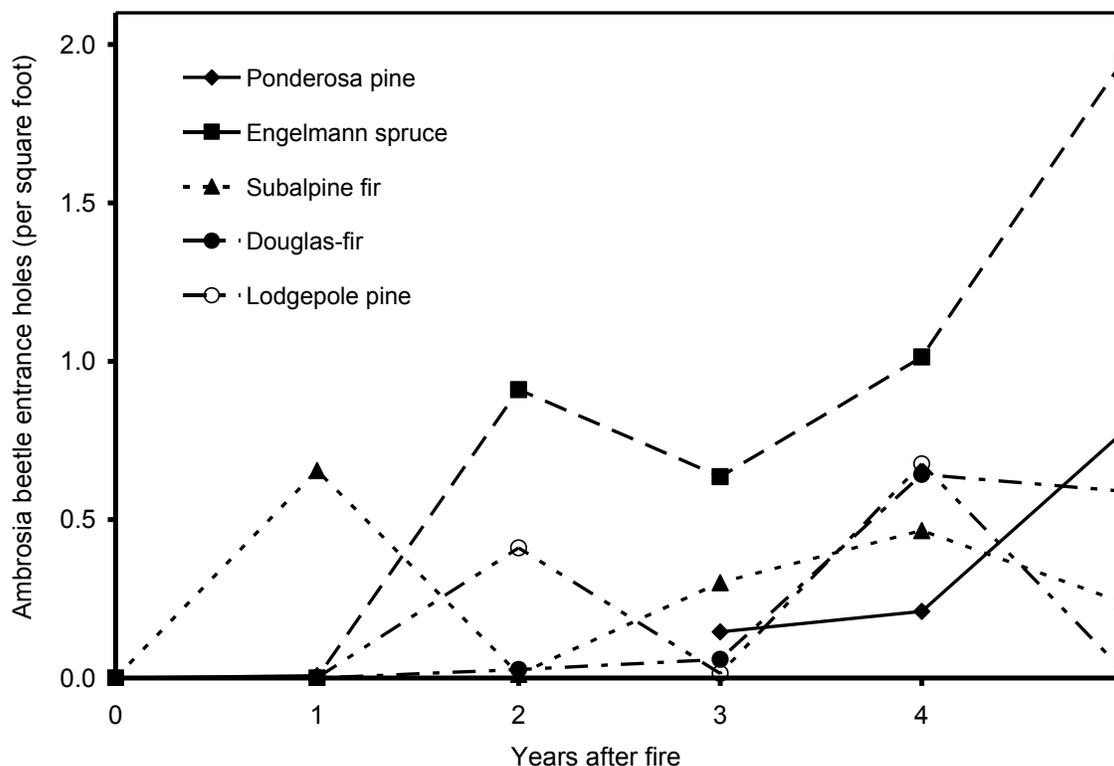


Figure 10. Density of ambrosia beetle entrance holes from 2002-2007.

### 3.3.2 Wood borers

Nineteen species of wood-boring insects were identified from emergence traps (Table 7). In some cases, emergence traps were improperly placed on host trees. This error was not discovered until the following year, so the list of insects obtained from fire-killed trees is qualitative rather than quantitative.

Table 7. Wood-boring insects emerging from fire-killed trees from study locations throughout the Rocky Mountain Region, 2002 – 2007.

Fire	Host	Family	Species
Battle Creek	PIPO	Buprestidae	<i>Acanthocinus obliquus</i>
		Buprestidae	<i>Buprestis consularis</i>
		Cerambycidae	<i>Monochamus scutellatus</i>
		Cerambycidae	<i>Stictoleptura canadensis</i>
		Siricidae	<i>Sirex clamator</i>
		Siricidae	<i>Xeris morrisoni</i>
		Bear Mtn. South	PICO
Buprestidae	<i>Chrysobothris dentipes</i>		
Buprestidae	<i>Dicera tenebrosa</i>		
Cerambycidae	<i>Monochamus scutellatus</i>		
Siricidae	<i>Sirex clamator</i>		
Siricidae	<i>Sirex cyaneus</i>		
Siricidae	<i>Sirex juvencus</i>		
Big Fish	ABB13	Buprestidae	<i>Acanthocinus obliquus</i>

Fire	Host	Family	Species
		Buprestidae	<i>Buprestis consularis</i>
		Buprestidae	<i>Buprestis maculativentris</i>
		Buprestidae	<i>Chrysobothris breviloba</i>
		Cerambycidae	<i>Monochamus scutellatus</i>
		Cerambycidae	<i>Phaenops gentilis</i>
		Siricidae	<i>Sirex clamator</i>
	PIEN	Buprestidae	<i>Acanthocinus obliquus</i>
		Buprestidae	<i>Chalcophora virginensis</i>
		Buprestidae	<i>Chrysobothris breviloba</i>
		Buprestidae	<i>Chrysobothris dentipes</i>
		Cerambycidae	<i>Xylotrechus longitarsis</i>
		Siricidae	<i>Sirex clamator</i>
		Siricidae	<i>Sirex cyaneus</i>
		Siricidae	<i>Sirex juvencus</i>
		Siricidae	<i>Xeris spectrum</i>
Bucktail	PIPO	Buprestidae	<i>Dicera tenebrosa</i>
		Cerambycidae	<i>Rhagium inquisitor</i>
		Siricidae	<i>Sirex clamator</i>
Grizzly Gulch	PIPO	Buprestidae	<i>Buprestis consularis</i>
		Buprestidae	<i>Dicera tenebrosa</i>
		Siricidae	<i>Sirex clamator</i>
Hayman	PSME	Buprestidae	<i>Acanthocinus obliquus</i>
		Buprestidae	<i>Buprestis consularis</i>
		Buprestidae	<i>Buprestis maculativentris</i>
		Buprestidae	<i>Chalcophora virginensis</i>
		Buprestidae	<i>Dicera tenebrosa</i>
		Cerambycidae	<i>Monochamus scutellatus</i>
		Cerambycidae	<i>Neoclytus muricatus</i>
		Cerambycidae	<i>Rhagium inquisitor</i>
		Cerambycidae	<i>Stictoleptura canadensis</i>
		Cerambycidae	<i>Xylotrechus longitarsis</i>
		Siricidae	<i>Sirex clamator</i>
		Siricidae	<i>Xeris morrisoni</i>
Million	PIPO	Buprestidae	<i>Acanthocinus obliquus</i>
		Buprestidae	<i>Acmaeops proteus</i>
		Cerambycidae	<i>Phaenops gentilis</i>
		Siricidae	<i>Sirex cyaneus</i>
Pass Creek	PICO	Buprestidae	<i>Chrysobothris breviloba</i>
		Buprestidae	<i>Chrysobothris dentipes</i>
		Buprestidae	<i>Dicera tenebrosa</i>
		Siricidae	<i>Sirex clamator</i>
		Siricidae	<i>Sirex cyaneus</i>
		Siricidae	<i>Sirex juvencus</i>

Fire	Host	Family	Species
West Beaver	ABBI3	Buprestidae	<i>Dicera tenebrosa</i>
		Cerambycidae	<i>Monochamus scutellatus</i>
		Siricidae	<i>Sirex cyaneus</i>
	PIEN	Buprestidae	<i>Chrysobothris dentipes</i>
		Buprestidae	<i>Acmaeops proteus</i>
		Siricidae	<i>Sirex cyaneus</i>

### 3.4 Stain

Sap stains (blue stains) were most distinct and widespread in the pine species, where sap stain reached 40-50% of total wood volume for all plots within two years of the fires (*Figure 11*). In the other species, stains were generally pale, difficult to detect in the saw cuts, and occupied small volumes of wood.

### 3.5 Wood decay

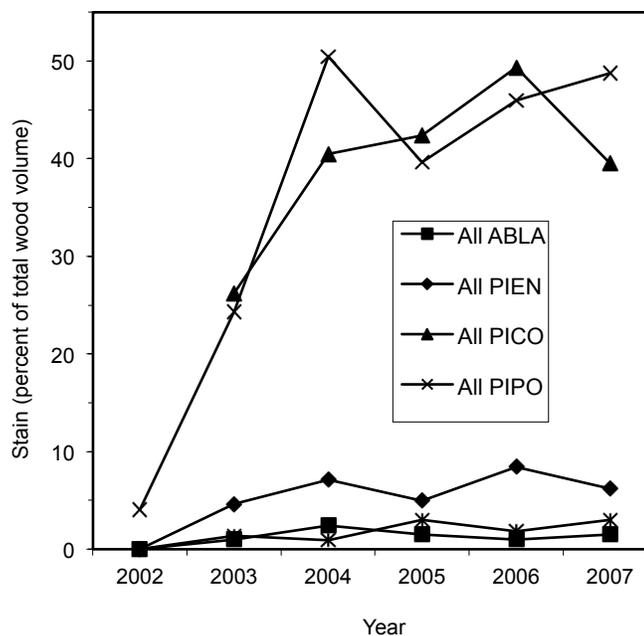
#### 3.5.1 Decay area on disks and volume

Internal decay (heart rot) and sap rot were measured on disks at the bottom and top of each log. The area decayed in each disk was calculated. The cubic volume of each log, tree and total sampled wood volume was calculated using Smalian's formula.

Internal decay is decay that was present in the living tree before the fire. In our sample, the order of tree species from greatest to least amount of internal decay was ABBI3 (grand mean 10.3%), PIEN (5.8%), PIPO and PSME (1.2%), and PICO (0.7%) (*Table 8*).

Internal decay volume varied greatly from year to year in our sample, presumably due to sampling error, but there is no evidence that this decay increased after death during the course of the study. Nor are the data consistent enough to conclude that certain stands had any more or less internal decay than other stands of the same species. However, sites did vary. For example, in ponderosa pine, internal decay varied from 0.4% at Bucktail to 2.3% at Battle Creek. Fir and spruce reversed at the two sites where they were sampled; fir had its highest decay at West Beaver, while spruce had its maximum at Big Fish.

Sap rot, as a proportion of disk area, was generally at or near maximum at the stump top (disk 0, *Figure 12*). It decreased in the middle positions, but rose to another peak in disk 3 (which was the merchantable top of many trees). In absolute terms, decay clearly progressed most rapidly at the base of the tree, but because that is the widest part of the stem it was not always the highest decay as a percent of wood area. Similarly, the peak in



*Figure 11.* Sap stain as a percentage of total wood volume of each species, by year.

the upper stem was probably in part an artifact of the small diameter: even limited sap rot affects a significant proportion of the disk area.

Table 8. Internal decay (heart rot) calculated as percentage of wood volume for each tree, averaged over species and fires.

Species	Fire	Year					Grand Mean	
		2002	2003	2004	2005	2006		2007
ABBI3	Big Fish	5.0	13.8	13.8	8.3	5.5	6.1	8.7
	West Beaver	12.7	15.3	15.8	6.9	16.5	9.4	12.8
	All ABBI3	8.1	14.4	14.6	7.8	9.9	7.3	<b>10.3</b>
PIEN	Big Fish	2.1	2.9	18.2	7.7	3.1	5.6	6.6
	West Beaver	2.7	2.4	2.3	2.8	3.8	0.0	2.3
	All PIEN	2.2	2.8	15.0	6.8	3.2	4.5	<b>5.8</b>
PICO	Bear Mtn. South		0.2	1.8	0.1	1.0	2.3	1.1
	Pass Creek		0.3	0.0	0	0.1	0.0	0.1
	All PICO		0.3	1.1	0.1	0.6	1.2	<b>0.7</b>
PIPO	Bucktail	0	0.1	1.6	0.4	0.2	0.2	0.4
	Million	0	0.8	0.0	0.1	0.3	4.3	0.9
	Battle Creek	0	5.8	7.5	0.0	0.4	0.0	2.3
	Grizzly Gulch	0	3.7	4.7	0.0	0.0	0.0	1.4
	All PIPO	0	2.3	3.2	0.2	0.2	1.0	<b>1.2</b>
PSME	Hayman	0.2	0.2	0.8	2.8	2.1	1.1	<b>1.2</b>
All species, all trees		2.2	3.8	6.4	3.0	2.8	2.7	<b>3.5</b>

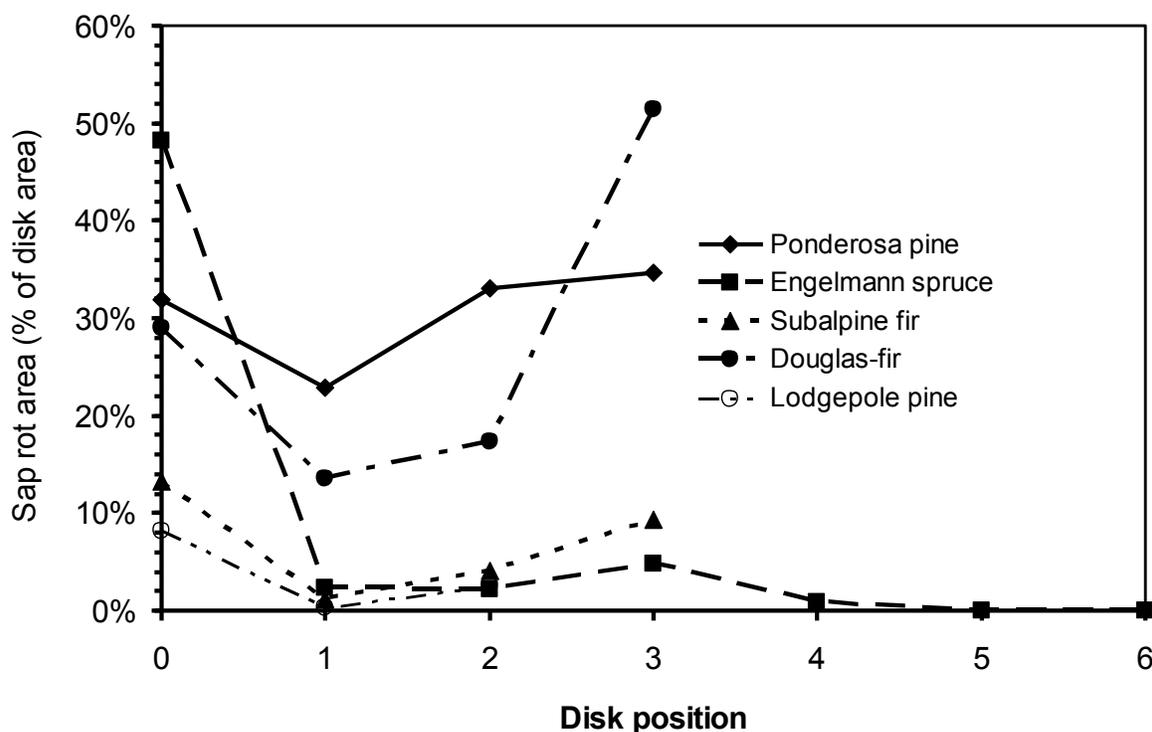


Figure 12. Sap rot in trees sampled in 2007, by species and disk position. Disk 0 is at the bottom of the first log (top of the stump), disk 1 is the top of the first log, disk 2 is the top of the second log, etc. Only the tallest trees are represented in the higher positions.

We calculated percentage of volume in sap rot two ways. First, we calculated the percentage wood volume that was sap-rotted in each tree, and averaged the trees over fires and species (*Table 9*). In this approach, small trees are weighted the same as big trees. No sap rot was detected in 2002, immediately after the fires. Very minor amounts of sap rot were detected in most species in 2003. In 2004 and/or 2005, sap rot increased greatly in all species. In the last two years, there was a general pattern of decreasing sap rot as a proportion of tree volume in some species. In general, the order of tree species, from greatest to least sap rot, was PIPO, PIEN, ABB13, PSME, and PICO. The increase in sap rot was particularly abrupt in PIPO.

In the second calculation, we summed total wood volume and sap-rot volume for each fire and species, and then calculated percentage sap rot from the totals (*Table 10*). Larger trees contribute more to the results than do small trees in this method. The patterns are generally the same as in the previous table, although numbers tend to be somewhat higher in most cases. This suggests that large trees have a greater percentage of sap rot than small trees in many cases.

*Table 9.* Sap rot calculated as percentage of wood volume for each tree, averaged over species and fire.

Species	Fire	Year					
		2002	2003	2004	2005	2006	2007
ABB13	Big Fish	0	0	8.75	7.44	24.80	11.09
	West Beaver	0	0.03	2.62	46.06	20.57	0.19
	All ABB13	0	0.01	6.30	22.89	23.11	6.90
PIEN	Big Fish	0	0	16.20	10.02	44.17	30.82
	West Beaver	0	0.85	22.32	27.55	25.18	14.36
	All PIEN	0	0.17	17.43	13.53	40.37	27.53
PICO	Bear Mtn. South		0.02	0.52	30.29	23.18	7.30
	Pass Creek		0	0.12	20.12	7.30	2.67
	All PICO		0.01	0.36	26.22	16.83	4.99
PIPO	Bucktail	0	0	0	27.55	44.53	22.93
	Million	0	0	6.77	31.34	26.83	21.34
	Battle Creek	0	0	0	85.40	63.03	24.25
	Grizzly Gulch	0	0	40.18	84.88	57.05	52.53
	All PIPO	0	0	10.43	53.99	47.49	29.45
PSME	Hayman	0	0.07	0.81	10.62	15.03	22.89
	All species, all trees	0	0.04	7.53	29.39	31.18	19.30

Table 10. Sap rot calculated as a percentage of total wood volume for each species and fire.

Species	Fire	Year					
		2002	2003	2004	2005	2006	2007
ABBI3	Big Fish	0	0	11.40	12.64	22.09	12.76
	West Beaver	0	0.04	2.49	53.14	10.94	0.13
	All ABBI3	0	0.02	6.45	33.84	13.72	6.47
PIEN	Big Fish	0	0	19.72	10.80	47.12	29.79
	West Beaver	0	1.11	27.89	31.29	24.16	10.44
	All PIEN	0	0.49	23.21	20.73	34.78	19.43
PICO	Bear Mountain South		0.01	0.20	29.73	23.15	7.86
	Pass Creek		0	0.21	19.54	8.38	2.23
	All PICO		0.01	0.20	25.58	17.71	5.23
PIPO	Bucktail	0	0	0	24.39	44.23	30.09
	Million	0	0	8.04	34.99	27.44	23.43
	Battle Creek	0	0	0	87.16	61.01	27.61
	Grizzly Gulch	0	0	39.64	84.54	55.04	57.45
	All PIPO	0	0	9.16	47.49	43.85	35.04
PSME	Hayman	0	0.03	0.83	11.87	15.39	21.99
	All species	0	0.12	8.99	31.92	27.59	21.46

### 3.5.2 Dry block density

In three tree species, block density generally decreased during the study as would be expected during decay, especially in the outer wood where sap rot begins and is usually most active (*Figure 13*). Subalpine fir and lodgepole pine showed no continuous decrease of density at all. The outer sapwood of Douglas-fir showed the greatest decrease, about 23% of the initial value. Certain years (year 2 for Engelmann spruce, year 3 for ponderosa pine and Douglas-fir) showed anomalous increases in density.

The data show a fairly consistent pattern of increasing density from the outer sapwood toward the inner wood at the pith. This pattern generally remained constant during the period of the study.

### 3.5.3 Decay fungi

At least 318 cultures of wood-decay fungi were isolated, of which 105 were identified at least to genus (*Table 11*). Among the 105 identified isolates, 38 species were represented. The greatest diversity of identified species was from ponderosa pine, Engelmann spruce, and subalpine fir. Although Douglas-fir was second only to ponderosa pine in the amount of sap rot at the end of the study (calculated as percent of total volume of all trees), it yielded only 6 identified isolates and 3 species. Only 34 of 213 unidentified isolates were from Douglas-fir. It is likely that common decay fungi in Douglas-fir were not amenable to isolation.

The most commonly isolated fungi are presented in the Discussion.

Table 11. Wood-decay fungi identified from cultures after isolation from fire-killed trees four years after mortality (2006).

Fungus	Number of isolations from tree species					Location
	ABBI3	PIEN	PICO	PIPO	PSME	
<i>Amylostereum chailletii</i>	4		3			Sapwood, lower stem
<i>Antrodia radiculosa</i>			1			Internal, base of stem
<i>Bjerkandera adusta</i>	1					Sapwood, lower stem
<i>Bondarzewia montana</i>	5	2				Sapwood and internal, mostly lower stem
<i>Botryobasidium botryosum</i>				1		Sapwood, base of stem
<i>Chaetoderma luna</i>	1					Sapwood, upper stem
<i>Coniophora puteana</i>		7	2	5	3	Sapwood, mostly base of stem
<i>Coniophora</i> sp.		3		1		Mostly sapwood, base to upper stem
<i>Dichomitus squalens</i>				6	2	Mostly sapwood, throughout stem
<i>Fomitopsis pinicola</i>				3	1	Sapwood, base to middle stem
<i>Galzinia incrustans</i>				1		Sapwood, upper stem
<i>Gleophyllum sepiarium</i>	1					Internal, base of stem
<i>Heterobasidion annosum</i>				1		Sapwood, base of stem
<i>Hypochnicium bombycinum</i>			2			Sapwood and internal, middle stem
<i>Hypochnicium punctulatum</i>				2		Sapwood, base of stem
<i>Meruliopsis corium</i>				2		Sapwood, base and middle stem
<i>Meruliopsis</i> sp.	1		1			Sapwood, middle stem
<i>Parmastomyces transmutans</i>				2		Sapwood, upper stem
<i>Peniophora</i> sp.		1				Sapwood, base of stem
<i>Peniophora gigantea</i>	2	3		1		Sapwood and internal, base to middle stem
<i>Peniophora piceae</i>		1				Internal, base of stem
<i>Peniophora pithya</i> or <i>septentrionalis</i>		2				Sapwood, base to upper stem
<i>Peniophora pseudopini</i>			1			Sapwood, middle stem
<i>Phaeolus schweinitzii</i>				1		Sapwood, middle stem
<i>Phanerochaete affinis</i>		6				Sapwood and internal, base to middle stem
<i>Phellinidium ferrugineofuscum</i>	1					Internal, base of stem
<i>Porodaedalea pini</i>		1				Internal, middle stem
<i>Phlebia coccineofulva</i>		1				Internal, middle stem
<i>Phlebia livida</i>	1					Internal, middle stem
<i>Phlebiopsis ravenelii</i>		1				Internal, middle stem
<i>Pleurotus</i> sp.				1		Sapwood, middle stem
<i>Pycnoporellus fulgens</i>	1					Sapwood, base of stem
<i>Pycnoporellus</i> sp.		1				Sapwood, base of stem
<i>Rigidoporus crocatus</i>				1		Sapwood, base of stem
<i>Sistotrema</i> sp.			1	1		Sapwood, base to middle stem
<i>Skeletocutis amorphus</i>				3		Sapwood, middle stem
<i>Stereum sanguinolentum</i>	5	2		1		Internal and sapwood, base to middle stem
<i>Trichaptum</i> sp.				1		Sapwood, upper stem
<b>TOTAL</b>	<b>23</b>	<b>31</b>	<b>11</b>	<b>34</b>	<b>6</b>	

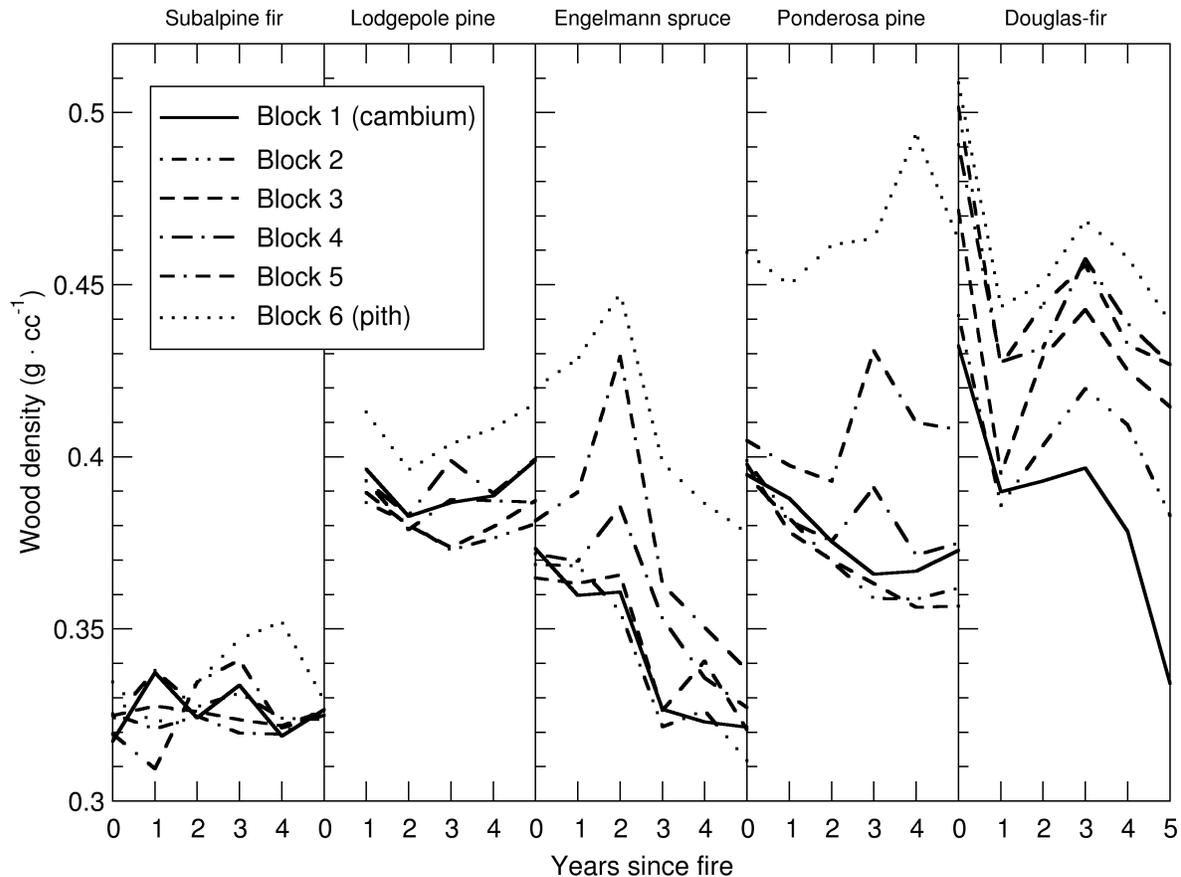


Figure 13. Changes in mean wood density (specific gravity) from 2002 (immediately after the fires) to 2007 (5 yr after the fires).

Fruiting of decay fungi was found on sample trees only once. The pouch fungus, *Cryptoporus volvatus*, was found on a ponderosa pine in the Battle Creek fire in 2003 (note that sap rot was not visibly detected at Battle Creek until 2005). The red-belt fungus, *Fomitopsis pinicola*, fruited commonly on fire-killed ponderosa pine in some plots, but did not fruit on our sample trees.

## 4. DISCUSSION

### 4.1 Defect

Within three years after the fires, fire-related defect and cubic volume loss in all species was high enough to substantially affect the economics of harvest activities for sawtimber production. Two to three years after the fire event a sale planner may want to consider increasing minimum cut tree DBH standards due to fire-related defects culling the smaller diameter trees.

Speed of salvage harvest planning and execution after fires is critical when considering sawtimber production. Sale terms should be short, 1-2 years, with termination dates at a maximum three years from the fire event. After 3 years from when a fire occurred, foresters should conduct a fall, buck, and scale study to determine sawlog merchantability. If severe checking is occurring and sap rot is beginning to show up, a firewood sale or other lower value product may be the best option.

Even secondary products in some species such as ponderosa pine, Douglas-fir and subalpine fir can be affected 3+ years out, which is due to the thicker bark retaining moisture and thus

contributing to sap rot. The chips from fire-killed timber generally have more fines because of decayed sapwood, thus reducing pulp yield. Chip value would decrease if the chips were of low quality and had to be sold for hog fuel instead of pulp for example.

## 4.2 Log density

By the end of the study, changes in log density appeared to be reaching a constant level. Also, within a species, log densities from different sites were nearly the same by the end, despite having differed considerably at the beginning of the study. Based on these results, significant changes in mean log density are not expected 4-5 years after trees have been killed by fire.

## 4.3 Insects

### 4.3.1 Insect damage

Wood borer galleries increased in most tree species up to four years after the fires. In Douglas-fir, the increase continued in the fifth year, and in ponderosa pine it peaked at three years. Borer galleries were highly variable among fires and individual trees. It appeared that, where fires severely damaged the bark and cambium, borers had difficulty becoming established and galleries were rare. Perhaps as a result, gallery density generally increased with tree height in spruce and fir, which have thin bark. However, this trend did not occur in lodgepole pine, which also has thin bark.

Boreholes of ambrosia beetles were less common and their pattern was erratic. They did not show an increasing trend during the study except in Engelmann spruce.

### 4.3.2 Wood borers

The activity of wood-boring insects plays an important role in the deterioration of fire-killed timber. The close linkage between fire-damaged trees and subsequent insect activity is demonstrated in the case of the wood-boring beetles in the genus *Melanophila* (Coleoptera: Buprestidae). The specialization of these insects with regards to fire killed hosts is indicated by the presence of infrared detecting organs on their bodies which help them to locate heat radiating from burned and smoldering wood (Evans 1966). There are three primary groups of insects which specialize on charred and fire-killed timber in the northern forests of North America. Two of these are families of beetles: Buprestidae (the metallic wood-boring beetles) and Cerambycidae (the long-horn beetles) (McCullough *et al.* 1998). The singular appearance of the larvae of these two families is alluded to by the common names for the immature forms – flat-headed borer (for Buprestidae) and round-headed borer (for Cerambycidae) (Furniss & Carolin 1977). The third major group of wood boring insects are the “horntails”, a group of broad-waisted wasps so named for the spike-like “horn” located on the tip of the abdomen of adults. The prominent ovipositional structures found on the females of “wood wasps” is another distinctive feature of the family Siricidae. An additional “group” of insects which specialize on dead timber are the ambrosia beetles. These small beetles (subfamilies Scolytinae and Platypodinae within Curculionidae) can frequently be found in wood killed by a variety of means, and are not considered to be specialists on fire-killed timber.

Although the direct impact of wood-boring insects on dead timber is relatively small in terms of the volume of wood that is consumed, there is a much larger influence due to the nature of the damage. The tunneling within the timber that result from insect activity allows deeper penetration by ambient moisture, as well as providing entrance courts for wood decay organisms, primarily fungi (Costello *et al.* 2011).

Wood-boring insects are some of the longest lived insects known. One species of North American Buprestidae (*Buprestis aurulenta*), has had documented life spans surpassing two decades; other species have similar records (Smith 1962). The variability of wood-borers' life span is largely dependent on localized conditions, especially availability of moisture (Zeng 1995). While some species of wood-boring insects may be observed emerging from hosts killed within the previous year, a synoptic record of all insects associated with fire-killed timber may take up to several decades to complete.

#### 4.4 Stain

Stain does not generally result in cull or defect, but it can affect value by reducing the grade of wood products. Stain was only abundant in the pine species, where it occupied 40-50% of wood volume in two years and did not increase much afterwards. It was generally a blue stain. Engelmann spruce had a less intense, grayish stain that reached only just over 5% of volume in about the same time. Negligible amounts of stain were seen in the other species.

#### 4.5 Decay

Decay was assessed four ways. First, decay was one of the defects that contributed to deductions during scaling (see sections 3.1 and 4.1). Second, decay that was visible on disk cross-sections was measured, and used to calculate decay as a proportion of log and tree volumes. Third, we measured changes in dry wood density of blocks taken from disks. Finally, in 2006, additional samples of decay were taken for isolation and identification of the causal fungi.

##### 4.5.1 Decay area on disks and volume

Pre-existing, internal decay (often called heart rot) is decay that was present in the living tree before the fire. It could conceivably expand in the dead tree, as it normally does slowly in living trees, but our data suggest that such expansion is negligible. Subalpine fir had substantially more internal decay than the other species (*Table 8*). This susceptibility to decay in the living tree is one reason for the relatively short lifespan of subalpine fir. Engelmann spruce was intermediate with about 5.8%, although an unusual plot in one year had 18%. The other species generally had much less internal decay, around 1% or less, but individual plots had as much as 7.5%.

One year after the fires, there was still little to no sap rot. Two years after the fire, there was substantial sap rot in some species and fires. Sap rot measured as a percentage of total volume was 40% in one ponderosa pine stand, and 20-28% of stand volume in spruce. By the third year, sap rot was substantial in all species with the exception of Douglas-fir with 12%. Ponderosa pine averaged 48%, with one fire as high as 87%. This increase of decay in ponderosa pine was particularly abrupt.

Sap rot appeared to decrease in some cases in the fourth and fifth year, which is impossible since decayed wood cannot become sound again. This may represent sampling error, which might have been remedied with larger numbers of trees or more restrictive sampling criteria. It may have been partly measurement error, since some judgment was involved in detecting early stages of decay, and crews changed from year to year. Finally, falling of trees and breakage may have played a role, since such logs were not measured, meaning the most advanced decay was removed from the sample population.

##### 4.5.2 Dry block density

Density (based on dry weight) of wood blocks cut from the trees did not provide a satisfactory measure of deterioration. Two species (subalpine fir and lodgepole pine) showed no decreasing

trend of density through the study, although other evidence shows they were clearly deteriorating over time.

In three tree species, data showed a general, though variable, decreasing trend of density representing decay, especially in the outer wood where sap rot begins and is usually most active. However, these density decreases do not match the pattern or degree of volume loss in the scaling measurements. The general trends of decreasing density were punctuated by anomalous peaks in density.

Wood density is normally a fairly sensitive measure of wood decay in laboratory studies, but in such studies, wood samples are from a single tree and clear wood with uniform growth rate, and are cut to a uniform size and shape. More importantly, the same block is typically measured before and after decay. In this study, a major source of variability was the original wood density before decay began, which undoubtedly varied widely among trees and blocks. For instance, anomalous peaks in density may have been due to disproportionate sampling of individual trees with dense wood in those years. This unavoidably reduces sensitivity in measurement of trends. Irregular block shapes and sizes also introduced measurement error, particularly when the block volume had to be measured with a micrometer rather than by water displacement. With highly degraded samples, volume could only be roughly estimated.

The measurement was sensitive insofar as it showed a fairly consistent increase in density from the outer to the inner wood (compare blocks 1-6 in *Figure 13*). This may be due to slower growth (denser wood) when trees were young and suppressed, or to the deposition of extractives in heartwood.

#### 4.5.3 Decay fungi

The fungi that we identified from isolations are undoubtedly only a small portion of the fungi involved in decaying these fire-killed trees. Only one-third of the isolated cultures could be identified with the techniques and time available to us, and the numbers suggest that more isolations would have yielded more new species. Because the majority of isolates were not identified, and countless more were not isolated, the 38 species we identified should be regarded as only a fraction of the diversity of decay fungi in these habitats.

The most frequently isolated fungus, with 17 isolates, was *Coniophora puteana*. It was isolated from all species in the study except subalpine fir, which is also known as a substrate (Ginns & Lefebvre 1998). Four additional isolates of *Coniophora* could not be identified to species, as the cultural characters of the species are not always distinct. *Coniophora* species cause brown rot of conifer wood, both in the butts of living trees and in dead trees, and even wood products in service (Zabel & Morrell 1992). *Coniophora* isolates were usually from the stem base, consistent with butt rot of the living trees, but in most cases only sap rot was noted in disks from which it was isolated. *Coniophora puteana* and *Coniophora* sp. were isolated occasionally from the tops of second logs. This suggests it can colonize stems after fires, either through bark fissures or entrance holes of insects.

The next most abundant fungi were *Dichomitus squalens* and *Stereum sanguinolentum*, both with 8 isolates. Both fungi are best known as causing decay in stems of living trees. *Dichomitus squalens* infects various conifers but especially ponderosa pine in the Southwest (Gilbertson & Ryvar den 1986) and the Black Hills (Anonymous 2010). In two cases, our isolations of *D. squalens* derived from internal infections in the living tree, but in the rest the colonization apparently occurred after the fire. *Stereum sanguinolentum* mostly infects firs and spruces but also other conifers. Most isolations of *S. sanguinolentum* could have derived from internal decay preceding the fire, but in at least two isolations were from disks with only sap rot and colonization apparently occurred after the fire. Both fungi cause white rot. The disease caused by *D. squalens* is called red ray rot, because of the reddish staining in a star-like pattern in the early stages of decay. Later it

forms indistinct white pockets in the wood, which eventually becomes a whitish, moist, soft, fibrous mass. Wood decayed by *S. sanguinolentum* also has a reddish stain at first (giving the disease the name red heart rot) and is firm, then light brown, dry, and friable with white mycelial sheets in the advanced stage.

The next most abundant fungi were *Amylostereum chailletii* and *Bondarzewia montana*, each with 7 isolates. The first is well known as a symbiont of siricid “wood wasps” (King 1966). The fungus is carried by female wood wasps in organs called mycangia, which have a duct that connects to the origin of the ovipositor. The female inserts her ovipositor through the bark of fire-killed and fire-damaged trees, then contracts certain muscles. This not only pushes eggs through the ovipositor, it also squeezes the mycangia, so that a mixture of eggs and fungal inoculum are pushed into the wood. The fungus kills any remaining live parenchyma in the area and partially decays the wood, improving the nutrition of the developing larvae. Our isolations were from subalpine fir and lodgepole pine, from sapwood primarily at the stem base, where wood wasps are most likely to be active, but also from the top of the first log.

Although *B. montana* was relatively common, it has not been previously reported in Colorado. We isolated it from spruce and fir, which are also common hosts in the Pacific Northwest, where the fungus is most common. It is primarily known as causing root and butt rot, but is not an important pathogen. Five of the isolations were from internal decay, but surprisingly five were from disk positions 1 or 2. This suggests that this fungus may cause decay of the upper stems of living trees, but it may also be able to colonize stems after fire.

*Heterobasidion annosum* causes an important root disease and sometimes butt rot in many forests around the northern hemisphere. There are two types of the fungus in North America (sometimes considered separate species): the S type primarily infects spruce and fir, and the P type primarily infects pines. In the Rocky Mountain Region, the P type has only been found in the Bessey Ranger District of the Nebraska National Forest, while the S type is known only from firs and spruces in southern Colorado. The one isolate we had of *H. annosum* was from a ponderosa pine in the Bucktail Fire on the Uncompahgre N.F. Using molecular methods, the isolate was identified as the P type (Worrall *et al.* 2010). This isolate was far from any known occurrences of *H. annosum*. It may have blown in from Utah, where the P type occurs. It was associated with sap rot at the stump disk, but there was no evidence of decay that had been in the living tree.

Benomyl was used as a selective ingredient in the isolation medium. This fungicide is widely used in isolating basidiomycetes, and tests have shown that it reduces or prevents growth of most groups of non-basidiomycetes, while having little effect on almost all basidiomycetes (Worrall 1991). However, during the isolations we noted that we were not isolating *Trichaptum abietinum*, which is a very common sap rotter of conifers. We isolated from fruit-bodies and conducted tests of the cultures with various concentrations of benomyl. Unfortunately, we found that *T. abietinum* was strongly inhibited by concentrations of benomyl that we used. Therefore, this fungus may be much more common in fire-killed trees than our data indicate. More recently, we have discovered that *Onnia tomentosa*, a root- and butt-rot fungus common in spruce, is also strongly inhibited by low concentrations of benomyl often used in selective media. In retrospect, it seems advisable to use a combination of selective and nonselective media for isolating unknown decay fungi.

The fruiting of *C. volvatus* before any sap rot was detected is consistent with its rapid appearance after tree mortality (Wright & Wright 1954). Although *C. volvatus* often fruits abundantly in moist climates, it apparently grows largely in the phloem and causes very limited sap rot. This fungus colonizes trees very early, and may have been replaced by other fungi before we conducted isolations in 2006.

In Memory of Entomologist Sheryl Costello



Photo by Anna Schoettle

## **ACKNOWLEDGMENTS**

The following Forest Health Protection employees or volunteer provided valuable field assistance with this project: Russell Beam, Sue Bookhout, Matt Cahir, Brian Carr, Anthony Clawson, Brandon Cochran, David Drons, Aspen Foreman, Ashley Hafner, Jennifer Klutsch, Gail Lawrence, Shawn (Oly) Olson, Suzie Parker, Jim Pratt, Diana Selby, Sarah Tharp, Brian Tracy, David (Hunter) Wade, and Angel Watkins. Kurt Allen, Kelly Burns, Sheryl Costello and Jeri Lyn Harris also provided assistance on some sites. Caley Gasch and Sheri Pucherelli entered and summarized much of the data. Casey Miller isolated and identified decay fungi.

In addition, the following District or Forest personnel helped locate field sites for the work and/or provided additional field assistance during sampling: Cary Green, Tim Garvey, Kirby Self, Christopher Finn, Roger Whiting, Chuck Morris, Christine Schneider, Ellen Jungck, John Cannon, Benjamin Manahan, and John Seeman.

Sheryl Costello (USDA Forest Service) and Boris Kondratieff (Colorado State University) assisted in identification of insects. Tom Harrington (Iowa State University) sequenced a fungal isolate for identification. The manuscript was kindly reviewed by Suzanne Bethers Marchetti, Kelly Burns, and Sheryl Costello.

The last two years of the six-year field portion of this project were funded by USDA Forest Service, Forest Health Monitoring, Evaluation Monitoring Program, project INT-F-06-04.

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