United States
Department of Agriculture

Okanogan and Wenatchee
National Forests
Wenatchee, Washington

March 2006

Wood changes in Fire-Killed Tree Species in Eastern Washington

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Summary:

Seven hundred and fifty trees killed by wildfires in the summer of 1994 were studied over five years to document changes that took place after tree death. Seven tree species, Douglas-fir, grand fir, subalpine fir, western larch, lodgepole pine, ponderosa pine, and Engelmann spruce from five wildfires in eastern Washington were in the study. Each year for five years, up to 150 trees were cut, measured, and observed. Each tree was examined for changes attributable to char, insect attack, fungal growth, and weather. The number of dead trees with char, stain, insect attacks, cracks, decay, bark loss, branch loss, and stem breakage was determined by years sine death. Volume of wood affected by cracking, stains, and decay was calculated for log positions and trees by years since death. Changes in fire-killed trees took place quickly and progressed with time. The changes varied greatly by tree species. Ponderosa pine and lodgepole pine had most of their sapwood stained one year after death. Thick-bark tree species, ponderosa pine, Douglas-fir, and grand fir were attacked rapidly by wood boring insects and decayed more quickly than thin bark species. Thin bark species cracked very quickly but were slower to break than thick bark species because they decayed slowly.

Wood Changes in Fire-Killed Eastern Washington Tree Species

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Introduction:

Tree-killing wildfires are common in eastern Washington. Fire-killed trees not harvested by man undergo myriad changes by numerous agents until ultimately they are totally decomposed. This can be described as natural recycling of the fire-killed trees. Information on the progression of changes that occur in fire-killed trees is needed by forest managers for many decisions. Although several studies have been published on wood deterioration in fire-killed trees in western North America, very few were done in environments typical of eastern Washington (2, 7, 15, 16, 17, 19, 20, 22). A literature review revealed limited information on fire induced changes for some species and no information for western larch and subalpine fir. Most studies had a strong emphasis on loss of merchantable wood volume to decay.

A study was done in eastern Washington to monitor, measure, and document changes in trees killed by 1994 wildfires. The study was designed to document changes that took place each year for five years after the trees had been killed.

Results of the five year wood changes study were reported in five separate yearly progress reports (9, 10, 11, 12, 13). We received several requests to prepare a summary report describing the wood changes that we observed and measured over the five year study period. This report consolidates the information we recorded for the five year period after the trees had been killed by wildfires.

Procedures:

In the fall of 1994 and spring of 1995, sampling plots were established in areas that had wildfires in July and August 1994 on the Colville, Okanogan, and Wenatchee National Forests in eastern Washington. Seven tree species were included: Douglas-fir, grand fir, subalpine fir, western larch, lodgepole pine, ponderosa pine, and Engelmann spruce. Four plots were established for each species, except Douglas-fir and grand fir which each had five plots.

Each plot had 25 standing trees of a single species killed outright by fire. Study trees had to be at least 6 inches DBH and have at least one merchantable size log. Each tree was affixed with a numbered tag and marked with paint bands to facilitate relocation.

Five trees were cut and measured in each plot in August and September 1995 through 1999. Procedures changed somewhat over the duration of the study. In 1995, one year after the trees had been killed, only trees cut for study were measured. From 1996 through 1999 (years 2 through 5) observations were made on all uncut plot trees before any were cut. Standing trees were examined for cracks, breakage, decay fungi sporophores, woodpecker feeding, and branch retention. Trees cut were measured to determine total height, height to 4-inch tops outside bark diameter, and height of bark scorch. Cut trees were divided and cut into four equal length logs. Logs were numbered 1 to 4 starting at the base. The top of log 4 was the location of the 4-inch top. Logs were examined for woodpecker feeding, insect activity, char, and sporophores. Beginning in 1997 at the end of the third anniversary of the wildfires, the amount of bark retained on each cut log was estimated to the closest 10 percent. Also starting in 1997, fine and coarse branch loss was estimated for each standing tree. Fine branches were 0.5 inches or less in diameter. Standing trees were rated as having less than 50 percent fine or coarse branch loss or 50 percent or more.

Five cross-sectional disks about 1 inch thick were removed from each of the cut trees at the following locations: stump top/ bottom log 1 - disk 1, top of log 1/bottom log 2 - disk 2, top of log 2/bottom log 3 - disk 3, top of log 3/bottom log 4 - disk 4, and top of log 4 at the 4 inch top - disk 5. A tag was stapled onto the upper surface of each disk identifying plot number, tree number, and disk position. Every disk was examined for cracks in the upper surface within 60 minutes of its collection. Cracks were counted and depth of penetration measured. We calculated the average crack depth at each disk position by using measurements of all cracks. We calculated the depth of the average deepest crack by using only the deepest crack measured on each of the cracked disks.

In the summer of1999, at which time the trees had been dead for 5 years, several trees remaining for sampling had broken and had substantial amounts of decay. These trees were still sampled, but it was not possible to count and measure cracks and wood borer holes in many disks because of the decay. Some severely decayed disks were not collected because the wood was too decomposed. In these cases diameters of the disks were measured and the disks were recorded as being 100 percent decayed.

Disks were taken to inside storage and thoroughly air-dried. The diameter of each disk was measured with a diameter tape after bark was removed. Top surfaces were sanded smooth to bring out color and texture changes caused by char, stain, and decay fungi. These changes were outlined on disk surfaces with colored pens. Only stains thought to be caused by fungi were outlined. Surface areas containing char, stain, and decay were measured by dot grid count for each disk. Insect galleries on the sides of disks were identified to causal insect to the best of our ability. Borer holes visible on sanded surfaces were counted and the depth of the deepest hole was measured on each disk. Borer galleries on the sides of disks but with no holes seen on the sanded surface were classified as "attacks". Borer holes seen on the sanded disk surfaces were classed as "holes". We calculated the depth of the average wood borer hole for each disk position by using measurements of all the holes. We calculated the depth of the average deepest hole by using only the deepest hole from each disk that had a wood borer hole.

Gross volume of each log was calculated by Smalian's formula. Tree volume was determined by adding the volume of the 4 logs. To calculate the volume of charred, stained, or decayed wood in each log, we added the number of square inches of char, stain, or decay at each end of the log, divided by 2, and then multiplied by log length. If stain or decay was seen at only one end of a log, the stain or decay was assumed to have extended one third of the log length. To calculate the volume of wood affected by cracking we took the average crack depth for disks collected at each end of each log. The average crack depth was subtracted from average total radius for each disk to calculate the diameter of the uncracked center. The volume of the uncracked center of the log was subtracted from the total calculated log volume to provide calculated volume affected by cracking.

The number and percent of sampled trees and disks with stain, decay, cracks, and borer attacks and holes were tabulated for each year. Wood volume calculated as stained, decayed, and affected by cracks was determined for each log and tree sampled.

Every tree in the study was examined for five wood changes: stain, decay, insect galleries, cracks, and char. Characteristics of these changes are as follows:

Wood stain. Wood color changes in fire-killed trees are caused by fungi, heat, and exposure to air. Most wood color changes are caused by fungi and are commonly called stains. Only stains believed to be caused by fungi were recorded in this study. Wood was classed as stained if it was colored darker than adjacent, apparently normal colored wood and was still firm. Practically all staining caused by fungi occurs in the sapwood because of the high moisture content and high concentrations of sugars

Decay. Several species of fungi and very few bacteria have enzymes that digest wood cell walls and contents, resulting in substantial loss of wood strength. Wood that was visibly softer than apparently normal wood and could be more easily penetrated with a sharp implement than adjacent apparently normal wood or was obviously decayed was classed as decayed. Wood that was considered to have incipient decay on the basis of being contiguous to obviously decayed wood and discolored or could be easily penetrated with a sharp implement was included as decayed wood.

Cracks. When wood in dead trees loses moisture it shrinks and splits. Cracks begin in the outermost sapwood and extend radially into the wood. Small cracks are also called checks or weather checks.

Insect galleries. Three groups of insects were found in fire-killed trees.

Wood borers in this study included insects in the Families *Buprestidae, Cerambycidae,* and *Siricidae*, commonly called flatheaded or metallic wood borers, roundheaded borers or long-horned beetles, and horntails, respectively. Female adult wood borers lay eggs under the bark of fire-killed trees. Many wood borers infest fire-killed trees the season they are killed, some while the trees are still smoldering. Larvae make meandering galleries under the bark, loosening it before tunneling into the wood. Wood borer larval galleries are packed with frass. Some species of wood borers infest the trees after the phloem/cambium tissues have fermented or dried, and even when the sapwood is decayed. Adult female horntails insert their eggs directly into the wood, sometimes up to one inch deep. Larvae mine entirely within the wood packing their galleries with fine boring dust.

Bark beetles also infest trees recently killed by fires. Bark beetle adults excavate galleries for egg laying between the bark and wood. Larval galleries are between the bark and wood and are packed with frass. Most bark beetles attacks occur 6 to 11 months after trees have been killed by wildfires, because most adult bark beetle flights occur from April to July, whereas most wildfires occur in July through September. Bark beetle larvae require fresh, succulent phloem and cambium tissues for food, they do not do well in fermented, cooked, or dried phloem and cambium tissues. Bark beetle larvae do not bore into the wood. Larvae feeding in phloem and cambium tissues cause the bark to loosen. Many bark beetles carry spores and mycelial fragments of fungi that stain and decay wood. Bark beetles inoculate large numbers of trees with fungi.

Ambrosia beetles are small insects that infest recently killed trees. They are also called pinhole borers. Ambrosia beetle adults bore into wood and excavate tunnels in which eggs are laid. They move chewed wood out of the tunnels. The adults carry a fungus that grows in the tunnels and is eaten by larvae. The fungus causes a dark stain around the perimeter of the tunnels. Ambrosia beetle tunnels typically are about 1/16th inch in diameter.

Char. Wood that was partially burned and blackened was classed as char.

Trees were also examined for woodpecker feeding, stem breakage, and bark and branch retention. Breaks were characterized as top-breaks if they were at or above the 4 inch top and stem breaks if they were lower. Bark retention was recorded in 10 percent increments for each log. Bark that was loosened but still adhering to the stem was considered to “be retained”.

Data from all four or five plots for each of seven tree species were combined to form “species data”. Wood changes in the fire-killed trees are described, largely as calculated averages in tables and charts.

Results:

Thirty study plots containing seven tree species killed by wildfires were established and followed for five years. Characteristics of the plots are shown in Table 1.

Table 1. Wood change study plots in eastern Washington.

Species	Fire	Av. DBH	Elevation	Aspect	Series
Douglas-fir	Poorman	11.7	2265	West	Douglas-fir
Douglas-fir	Tyee	15.7	3000	SE, Flat	Grand fir
Douglas-fir	Tyee	15.6	3060	SW, Var.	Grand fir
Douglas-fir	Bannon	14.1	3300	NE	Douglas-fir
Douglas-fir	Whiteface	20.6	5300	SE	Subalpine fir
Grand fir	Tyee	16.4	2300	Variable	Grand fir
Grand fir	Tyee	13.7	3300	SE	Subalpine fir
Grand fir	Tyee	14.6	3350	Flat, NE	Grand fir
Grand fir	Tyee	13.6	3600	SE	Subalpine fir
Grand fir	Tyee	17.8	5000	North	Subalpine fir
Subalpine fir	Whiteface	11.5	5200	SE	Subalpine fir
Subalpine fir	Whiteface	12.9	5200	SE	Subalpine fir
Subalpine fir	Whiteface	12.8	5320	S, Var.	Subalpine fir
Subalpine fir	Tyee	13.8	6000	SE	Subalpine fir
Western larch	Bannon	11.0	3800	North	Douglas-fir
Western larch	Bannon	11.2	4000	North	Douglas-fir
Western larch	Bannon	9.9	4150	North	Douglas-fir
Western larch	Copper	15.4	5000	SE, Var.	Subalpine fir
Lodgepole pine	Tyee	11.5	4440	Flat	Subalpine fir
Lodgepole pine	Tyee	9.5	4600	South	Subalpine fir
Lodgepole pine	Tyee	14.5	5700	SE	Subalpine fir
Lodgepole pine	Thunder	8.4	6400	West	Subalpine fir
Ponderosa pine	Tyee	14.9	2320	Flat	Douglas-fir
Ponderosa pine	Tyee	14.2	3000	East	Douglas-fir
Ponderosa pine	Tyee	14.0	3200	East	Grand fir
Ponderosa pine	Tyee	13.8	3540	East, Flat	Douglas-fir
Engelmann spruce	Whiteface	19.1	5200	SE	Subalpine fir
Engelmann spruce	Thunder	15.0	5560	NW	Subalpine fir
Engelmann spruce	Thunder	16.5	5900	South	Subalpine fir
Engelmann spruce	Thunder	17.6	6000	North	Subalpine fir

Over the five years, 725 trees were studied. A total of 2,900 logs and 3,625 disks were cut and examined.

Fire-killed trees changed quickly from time of death. Numerous agents were responsible for the changes. Patterns of changes over the five year period were identified. Agents of wood changes in the fire-killed trees, timing of changes, and magnitude of changes varied considerably between the seven tree species in the study. Even within a tree species, changes varied somewhat between the plots.

Very little wood volume in any of the seven tree species was affected by charring. Most charred wood was associated with wood exposed by injuries predating fires. Char associated with burnt branch stubs was not included. The percent of sampled trees with char and wood volumes affected are shown in Table 2.

Table 2. Percent fire-killed trees with char and wood volume affected.

Species	% trees with char	% Char vol. Affected, all trees	% Char vol. Affected, charred trees only
Douglas-fir	6.1	0.01	0.12
Grand fir	9.9	0.02	0.19
Subalpine fir	38.6	0.10	0.21
Western larch	5.6	0.01	0.10
Lodgepole pine	16.0	0.02	0.17
Ponderosa pine	5.0	0.01	0.15
Engelmann spruce	19.2	0.01	0.08

Douglas-fir

One Douglas-fir plot on the Wenatchee National Forest could not be used in years four and five because all remaining tagged trees were removed by salvage logging.

Percent Douglas-fir trees with stain, cracks, borer holes, and wood decay are shown in Tables 3 and 4 and Figure 1.

Table 3. Percent fire-killed Douglas-firs with stain, cracks, borer holes, and decay by years since death.

Wood Change	Year 1	Year 2	Year 3	Year 4	Year 5
Stain	73	100	100	100	NC*
Cracks	38	88	96	100	100
Borer holes	77	96	100	100	NC*
Decay	0	56	72	100	95

* Not Calculable due to decay.

Table 4. Percent wood volume affected by stain, cracks, and decay in fire-killed Douglas-firs by years since death.

Wood Change	Year 1	Year 2	Year 3	Year 4	Year 5
Stain	3.1	9.0	22.4	NC*	NC*
Cracks	6.5	19.0	28.8	30.9	40.3
Decay	0.0	1.1	3.3	6.4	16.4

* Not Calculable due to decay.

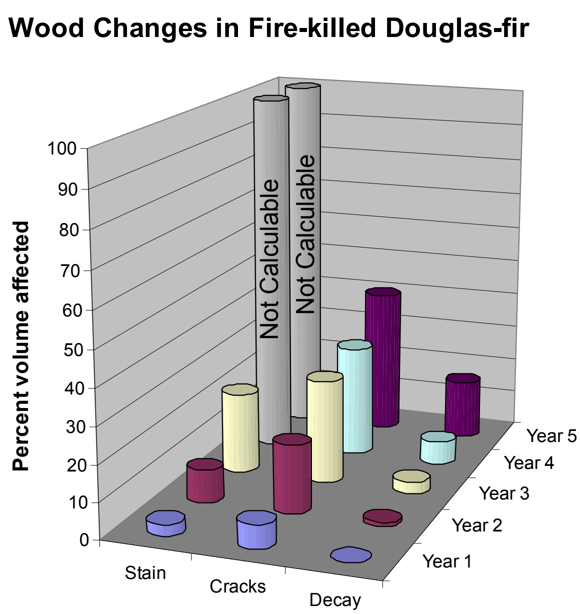


Fig 1. Volume of wood in fire-killed Douglas-firs affected by stain, cracks, and decay by years since death.

Sapwood stain: Sapwood stain was found in 73 percent of the fire-killed Douglas-firs sampled one year after the trees had been killed. The patches of stain were small and discontinuous in the sapwood. Stain seldom penetrated more than one inch into the sapwood, consequently volume stained was small. At year one, mid-bole disk positions 2 and 3 had the highest incidences of stain, corresponding to bark beetle and wood borer attack sites. All trees sampled at year two had stain showing on the disks and the percent volume wood stained increased as the stain fungi spread in the wood. Number of disks stained and percent volume wood stained both peaked in sampled trees at year three. Most Douglas-fir sapwood was stained by the third year fire anniversary. Wood classed as stained decreased in years four and five as the incidence and volume of wood decay increased. Wood that had been stained became decayed as stain-causing fungi were succeeded by decay-causing fungi (Tables A.1 and A.2).

Cracks: Thirty-eight percent of the sampled fire-killed Douglas-firs had cracks in the disks at the end of the first year. After two years, 88 percent of the trees had cracks, even though none of the sampled trees had lost bark. The average number of cracks per disk increased yearly through year four. Disk 1 from the stump area always had the lowest incidence of cracks due to the high moisture content of the wood and tight bark retention. Disks from positions 3, 4, and 5 were more likely to be cracked than disks 1 and 2. Average crack depth increased slightly, mainly because depth of the average deepest crack increased slightly each of the first four years for most disk positions. The volume of wood affected by cracking increased every year, with large increases taking place in years two and three. At year five most of the sapwood was decayed and it became impossible to count and measure cracks on several disks. Log 1 always had the lowest percentage of wood affected by cracking. Douglas-firs experienced the lowest percentage of volume affected by cracking of the seven tree species monitored (Tables A.3 and A.4).

Decay: No Douglas-firs sampled at the end of year one had any decay. At the end of year two more than half the trees had spots of sapwood decay. Pouch fungus (*Cryptoporus volvatus)* conks were found on slightly more than half the trees at year two as a result of Douglas-fir beetle and wood borer infestations in year one. One red belt fungus (*Fomitopsis pinicola)* conk was found in year three, on seven trees in year four, and two trees in year five. At year four all sampled trees had decay. *Trichaptum abietinum* conks, cause of pitted saprot, were found on three trees in year four. In years two and three the highest incidence of decay was found in disk position 2, but at year four position 1 disks had the greatest incidence. Disks 4 and 5 collected from standing trees were less likely to have decay than the lower disks. Percent wood volume decayed was small at years two and three, increased to slightly more than 6 percent at year four and increased substantially in year five. At the end of 5 years almost all the sapwood was decayed and several trees had broken because of the decayed wood. Conks of *Gleophyllum sepiarium*, cause of brown cubical saprot, were found on one tree at year five. The incidence of decay varied considerably between plots. The Whiteface plot on the Okanogan National Forest had large, slow-growing trees that had much smaller amounts of decay than Douglas-firs in the other plots (Tables A.5 and A.6).

Wood borers: Wood borers quickly infested fire-killed Douglas-firs. Most trees were probably infested in 1994, the year the trees were killed by fires. Twenty-five of twenty-six sampled trees were infested at the end of year one. Many of the trees had holes extending into the disks at one year. Borers continued to infest trees between year one and two. At year two, 96 percent of the disks had borer holes and live larvae were commonly found between the bark and wood and in the wood. Disks at all positions had holes, but position 5 at the 4-inch tops had the lowest percentage of disks with holes. Depth of the average deepest hole increased each of the first four years in disk positions 1 and 2. The average number of holes per disk increased each of the first 4 years at every disk position. Douglas-fir had the second highest average number of wood borer holes per disk, exceeded only by western larch (Table A.7).

Other insects: Twenty-one fire-killed Douglas-firs had galleries of the Douglas-fir engraver (*Scolytus unispinosus*). Galleries made by this insect were small and had associated stain. They were always found under thin, uncharred bark. Only three trees had recognizable Douglas-fir beetle (*Dendroctonus pseudotsugae*) galleries. Many trees probably had been infested by Douglas-fir beetles because 69 had conks of pouch fungus, which is mainly vectored by bark beetles. Wood borer larvae in the phloem/cambium tissues were so abundant they probably overran Douglas-fir beetle larval galleries or consumed fresh phloem/cambium tissues before bark beetle larvae could use them.

Snag failures: The tops of two trees broke above the 4-inch diameter in year three. Three trees broke below the 4-inch diameter in year four. Three trees broke and two trees had top breaks in year five. Breakage was most rapid in small diameter trees.

Bark loss: Fire-killed Douglas-firs lost almost no bark over the five year period. Bark was loosened by the actions of wood borers, bark beetles, and decay fungi, but very little fell from the trees.

Branch loss: Douglas-firs experienced rather small losses of branches through year four when only 12 percent of the standing trees had lost more than 50 percent of their fine branches. Branch loss increased tremendously in year 5 when 79 percent of the trees had lost more than half the fine branches and 26 percent had lost more than half their coarse branches.

Woodpecker feeding: Woodpeckers began to feed on insects in fire-killed Douglas-firs in the first year and continued throughout the five years. Some study trees apparently did not have any woodpecker feeding in years one through three but by year four all standing plot trees had been fed upon. Woodpeckers appeared to resume actively foraging on several Douglas-firs between years four and five after foraging slowed in year three. Several trees sampled at year five that had previously been foraged had fresh foraging for wood borers. Most fire-killed Douglas-firs had numerous woodpecker foraging marks.

Yearly summary highlights of changes in fire-killed Douglas-firs:

Year One: Almost no wood was affected by stain, cracks, and decay . Most trees were infested by wood borers. Wood borer holes extended into the sapwood. Woodpecker feeding was common.

Year Two: Cracks (weather checks) were common in the dead trees and almost 20% of the volume was affected. Little volume was affected by sapwood stains. Many trees had pouch fungus conks but virtually no sapwood decay. Wood borer holes were common in the sapwood. Woodpecker feeding was common.

Year Three: Almost all sapwood was stained. Slightly less than 30% of the volume was affected by cracks. Sapwood decay was common but volume affected was small.

Year Four: Conks of the red belt fungus became more common. Much of the sapwood was decayed. Tree tops began to break.

Year Five: Most of the sapwood was decayed but heartwood was still largely sound. Stem breakage was common due to sapwood decay. Wood borers were infesting trees and woodpeckers are feeding on them.

Grand fir

Percent fire-killed grand fir trees with stain, cracks, borer holes, and wood decay are shown in Tables 5 and 6 and Figure 2.

Table 5. Percent fire-killed grand firs with stain, cracks, borer holes, and decay by years since death.

Wood Change	Year 1	Year 2	Year 3	Year 4	Year 5
Stain	100	100	100	100	NC*
Cracks	84	100	100	100	NC*
Borer holes	90	100	100	91	NC*
Decay	56	84	84	87	100

Not Calculable due to decay.

Table 6. Percent wood volume affected by stain, cracks, and decay in fire-killed grand firs by years since death.

Wood Change	Year 1	Year 2	Year 3	Year 4	Year 5
Stain	10.9	8.0	22.2	36.6	NC*
Cracks	14.0	35.9	52.5	NC*	NC*
Decay	0.4	1.8	5.0	18.8	39.8

Not Calculable due to decay.

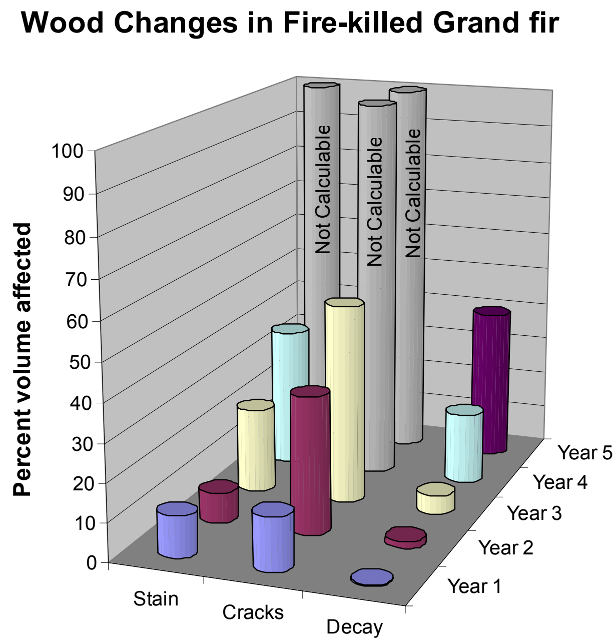


Fig 2. Volume of wood of fire-killed grand firs affected by stain, cracks, and decay by years since death.

Sapwood stain: Sapwood stain was found in every fire-killed grand fir sampled one year after the trees had been killed. Stain was common at every disk position, but position 5 consistently had the fewest stained disks. The percent wood volume stained did not increase in year two but increased in years three and four as the stain fungi spread in the wood. Most stain was black to violet. At year five volume of wood stained decreased substantially as large volumes of previously stained wood decayed (Tables A.8 and A.9).

Cracks: Grand firs cracked quickly. Half the disks collected from fire-killed grand firs dead one year contained cracks and 84 percent of the trees had cracks. After two years all sampled trees had cracks. Disk position 1 was least likely to have cracks. The average crack depth and the average deepest crack depth increased slightly each of the first three years. Several disks collected at year two had cracks that extended to their centers. Forty percent of the disks collected at year four were cracked to the centers. Wood volume affected by cracking was moderately high after one year and increased substantially in years two and three. Many cracks were obscured and could not be measured at years four and five as the wood became decayed. The thin bark of grand fir, which quickly sloughed from the trees, contributed to the rapid cracking. Much of the decay in grand firs appeared to be associated with cracks (Tables A.10 and A.11).

Decay: Wood decay appeared fastest in fire-killed grand firs. Fourteen of twenty-five grand firs sampled at the end of year one had decay. The percentage of disks with decay decreased as height increased; disks from position 1 always had the most decay. Pouch fungus conks were found on three trees cut at year one and were common in year two. Percent average tree wood volume decayed was small for the first two years then increased considerably at year three, and then had large increases in years four and five. The only sporophores found on grand firs were the pouch fungus. Bark char influenced the presence of pouch fungus conks. On 85 percent of the grand firs with conks, the conks were located above bark char height. The reason for this is fir engraver, which is the major vector of the pouch fungus in grand fir, avoided making entrance holes through charred bark (Tables A.12 and A.13).

Wood borers: Ninety percent of the grand firs sampled at the end of year one had been infested by wood borers. At the end of year two, all trees sampled had been infested. At years one and two, disk positions 2 and 3 had the highest percentages of disks with borer holes. Position 5 always had the lowest percentage of disks with holes. The average number of holes per disk increased for each of the first four years for disk position 1. Depth of the average deepest hole increased each of the first four years for disk positions 1 and 2 (Table A.14).

Other insects: Sixty three percent of the fire-killed grand firs had fir engraver galleries. All fir engraver galleries appeared to have been made in year one. Fir engraver galleries were never found under scorched bark. Eight trees had ambrosia beetle galleries.

Snag failures: One grand fir broke below the 4-inch top in year two. One tree broke and another had a top break in year three. Five grand firs broke and 11 had top breaks in year four. In year five, two trees broke and one had a top break. In years four and five, several grand firs that failed broke at the root collar. The outer ¼ inch to ½ inch of these trees was case-hardened and the wood underneath was very rotted where they broke.

Bark loss: Bark loss began at the bases of fire-killed grand firs. Less than half the bark was retained on log position one at the end of three years, but almost three quarters of the bark was retained but loose on log positions 3 and 4. Bark loss continued from log position 1 through year five.

Branch loss: Grand firs lost branches quickly. At the end of three years, 36 percent of the trees had lost more than half their fine branches. At the end of five years, all standing trees had lost more than half their fine branches and 70 percent lost more than half their coarse branches.

Woodpecker feeding: Woodpeckers appeared to forage on fire-killed grand firs throughout the five years, but the most active feeding was in year one. Most trees that had woodpecker feeding sustained light foraging.

Yearly summary highlights of changes in fire-killed grand firs:

Year One: Most of the trees had cracks at one year and an average of 14% of the volume was affected. Sapwood stain was common but volume affected was small, Sapwood decay was small. Most trees were infested by wood borers and had been foraged by woodpeckers. Wood borer holes extended into the sapwood, particularly at mid-bole positions. Fir engravers infested many of the fire-killed trees above scorched bark.

Year Two: All trees had cracks and 35% of the volume was affected. Pouch fungus conks were found on many trees but wood volume decayed was small.

Year Three: More than 50% of the volume was affected by cracks. Sapwood decay was common in the basal log. Most trees lost more than half their bark. Little wood volume was available for salvage. Stem breakage began.

Year Four: Most sapwood in the basal log was decayed. Top and stem breakage was common.

Year Five: All sapwood in the basal log was decayed. Top and stem breaks were common. Little wood volume was available for salvage.

Subalpine fir

Percent fire-killed subalpine firs with stain, cracks, borer holes, and wood decay are shown in Tables 7 and 8 and Figure 3.

Table 7. Percent fire-killed subalpine firs with stain, cracks, borer holes, and decay by years since death.

Wood Change	Year 1	Year 2	Year 3	Year 4	Year 5
Stain	95	100	100	100	100
Cracks	95	100	100	100	100
Borer holes	35	35	20	35	29
Decay	5	20	10	50	76

Table. 8. Percent wood volume affected by stain, cracks, and decay in fire-killed subalpine firs by years since death.

Wood Change	Year 1	Year 2	Year 3	Year 4	Year 5
Stain	6.0	4.9	6.3	6.4	5.5
Cracks	38.3	59.0	68.7	65.2	68.4
Decay	0.0	0.0	0.1	1.4	4.0

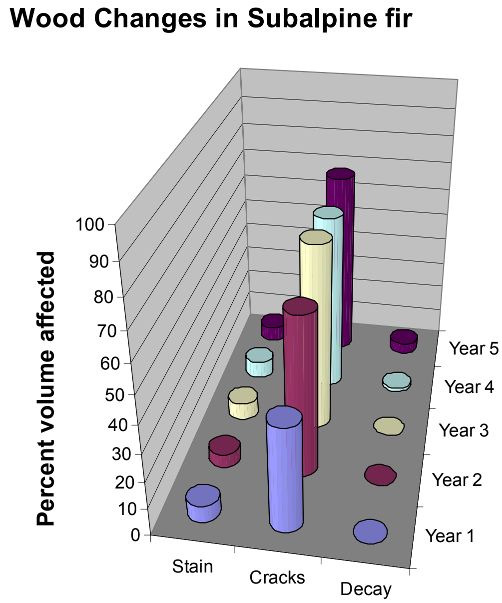


Fig. 3. Volume of wood of fire-killed subalpine firs affected by stain, cracks, and decay by years since death.

Sapwood stain: Nineteen of twenty fire-killed subalpine firs sampled one year after death had stain in the sapwood. Stain occurred in relatively small discontinuous spots and rarely penetrated more than 0.5 inches deep. The percentage of disks stained increased in year two and then stabilized. The average surface area of disks stained never exceeded 11 percent. The volume of wood stained remained unchanged throughout the five year period. The wood of the fire-killed subalpine firs appeared to be too dry to enable stain fungi to spread after the first year. Subalpine firs had the lowest percent wood volume stained of the seven tree species monitored (Tables A.15 and A.16).

Cracks: Nineteen of twenty fire-killed subalpine firs sampled at one year had cracks and almost 80 percent of the disks contained cracks. After two years, all disks were cracked. Subalpine fir cracked more rapidly than other species. Average crack depth did not change much over five years but the average deepest crack depth did increase at almost every disk position. Forty percent of disks collected at position 4 at year one were already cracked to their centers. More than one third of the wood volume was affected by cracking after one year and percent volume affected increased in years two and three. At the end of year three, 68 percent of the average tree volume was affected by cracks. The thin bark of subalpine firs and severe fire intensities at most subalpine fir plots contributed to the rapid cracking (Tables A.17 and A.18).

Decay: Wood decay was common, but not extensive in fire-killed subalpine firs over the five years. Only one tree had decay at year one but by year five about three quarters of the trees had some decay. Decay incidence was greatest in disk position 1 as the decay fungi appeared to be spreading upward from the roots and root collars. Higher disk positions had very low incidences of decay because the wood was too dry to support fungal growth most of the time. Only 4 percent of the wood volume was affected by decay after five years. No decay fungi sporophores were found on subalpine firs (Tables A.19 and A.20).

Wood borers: Fire-killed subalpine firs were only lightly infested by wood borers. The percent of disks with holes never exceeded 21. Disk position 1 had the highest incidence of attacks. Several borer attacks apparently did not result in holes into the wood. Disk positions 4 and 5 had very few holes. It appeared that practically all the wood borer attacks took place in year one (Table A.21).

Other insects: No bark beetle galleries were found on any of the fire-killed subalpine firs. Ambrosia beetle galleries were found on only six trees.

Snag failures: No fire-killed subalpine firs had stem breaks during the five years. Two trees had top breaks in year three. One tree had a top break in year four and one tree had a top break in year five.

Bark loss: Fire-killed subalpine firs lost bark quickly. After three years, only 22 percent of the bark was retained on log position 1. About two-thirds of the bark was retained on log positions 3 and 4. Bark retention did not change in years four and five.

Branch loss: Subalpine firs lost branches faster than other species. At three years, 58 percent lost more than half their fine branches.

Woodpecker feeding: Woodpecker feeding was found on only three trees over the five years. The trees had just a few scattered foraging marks.

Yearly summary highlights of changes in fire-killed subalpine firs

Year One: Almost all trees had cracks and almost 40% of the volume was affected.
Year Two: All trees had many deep cracks and almost 60% of the volume was affected. Most trees lost more than half their bark, particularly from the bases.
Year Three: All trees had many deep cracks.
Year Four: All trees had many deep cracks and most had lost most of their bark and fine branches.
Year Five: No trees had stem breaks. Decay volume was small. Almost 70% of the volume was affected by cracks.

Western larch

Percent fire-killed western larch with stain, cracks, borer holes, and wood decay are shown in Tables 9 and 10 and Figure 4.

Table 9. Percent fire-killed western larch with stain, cracks, borer holes, and decay by years since death.

Wood Change	Year 1	Year 2	Year 3	Year 4	Year 5
Stain	95	100	100	100	100
Cracks	65	100	9	100	100
Borer holes	100	100	100	100	100
Decay	10	0	15	7	20

Table 10. Percent wood volume affected by stain, cracks, and decay in fire-killed western larch by years since death.

Wood Change	Year 1	Year 2	Year 3	Year 4	Year 5
Stain	5.7	20.9	23.7	23.1	21.9
Cracks	10.5	39.1	55.4	78.6	80.3
Decay	0.0	0.0	0.2	0.01	0.2

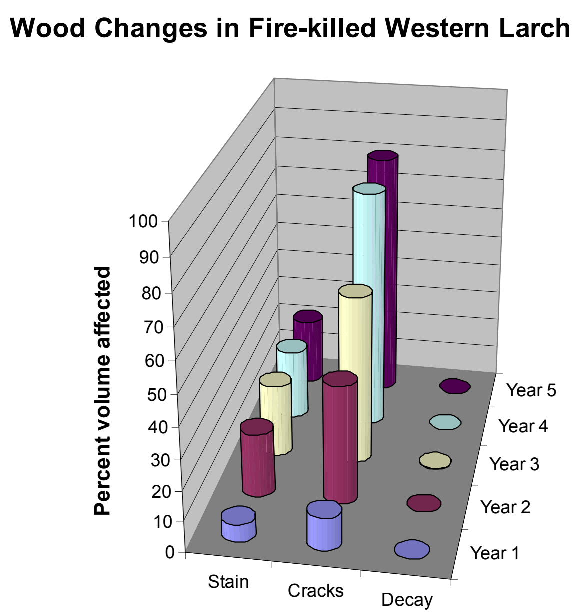


Fig. 4. Volume of wood of fire-killed western larch affected by stain, cracks, and decay by years since death.

One western larch plot on the Colville National Forest could not be used at years four and five because severe flooding destroyed access.

Sapwood stain: Nineteen of twenty fire-killed larch sampled one year after death had stain in the sapwood. More than three-quarters of the disks collected at year one had stain. All stain was confined to the sapwood. The volume of wood stained increased in year two and then stabilized as almost all the sapwood had been stained. Wood appeared to be too dry to enable stain fungi to spread by the end of the second year. Most stain appeared to be associated with attacks by wood borers. At year one almost all disks collected from the Colville National Forest plot had stain and contained large numbers of wood borers. Unlike several other tree species, stained wood in western larch did not become decayed at the end of five years (Tables A.22 and A.23).

Cracks: Thirteen of the fifteen larch sampled on the relatively dry Okanogan plots cracked by the end of year one, but none of the five larch sampled on the more moist Colville plot were cracked. All larch sampled at year two had cracks, including those from the Colville plot. Average crack depth increased slightly each of the first three years. Depth of the average deepest crack increased each year. Fifty-nine percent of the disks collected at year four were cracked to the centers. At the end of five years, cracks extended deep into the lowest three disk positions. Wood volume affected by cracks increased substantially in years two, three, and four to 39 percent, 55 percent, and 79 percent, respectively. Western larch had higher percentages of wood volume affected by cracks than the other six tree species (Tables A.24 and A.25).

Decay: Fire-killed western larch experienced very low losses to decay over five years. Spots of decay typically were very small. Decay was never found in more than 4 percent of the disks. Less than 1 percent of the wood volume was affected by decay after five years. In the trees that did have decay only 1.2 percent volume was affected after five years. In the few trees that had decay there was a slight tendency for disk position 1 to be affected more than the other positions. Two trees had wood decay sporophores, the pouch fungus (Tables A.26 and A.27).

Wood borers: Fire-killed western larch was more severely infested by wood borers than the other species. All trees sampled at the end of year one had been infested and every tree sampled over the five years was infested. All disk positions except 5 had very high percentages of disks with holes. The average number of holes per disk increased slightly each year for positions 1 and 2. Western larch had more holes per disk than the other tree species (Table A.28).

Other insects: No bark beetle galleries were seen on any larch. Three trees had ambrosia beetle galleries.

Snag failures: No larch experienced stem breaks over the five years. One tree had a top break at year four. Western larch had the lowest rate of snag failures.

Bark loss: Fire-killed western larch lost almost no bark over the five years. About 10 percent of the bark was missing from log position 1 at year five.

Branch loss: Western larch experienced little loss of branches until year five when 40 percent of the remaining trees lost more than half the fines and 27 percent lost more than half the coarse branches.

Woodpecker feeding: Almost all fire-killed western larch had woodpeckers foraging for wood borers at one year. After three years, all standing trees had been foraged on by woodpeckers. Woodpecker foraging was more abundant on larch than other species.

Yearly summary highlights of changes in fire-killed western larch:

Year One: Almost all the trees had been infested by wood borers. Wood borer holes were very common in the sapwood. Almost all trees had stain confined to the sapwood. Woodpecker foraging was common.
Year Two: All trees had been infested by wood borers and foraged on by woodpeckers. All trees had cracks and almost 40% of the volume was affected. Most of the sapwood was stained.
Year Three: Cracks affected about 55% of the volume.
Year Four: About 80% of the volume was affected by cracking.
Year Five: Almost 80% of the volume was affected by cracks. Very little volume was affected by decay. No snags had stem breaks.

Lodgepole pine

Percent fire-killed lodgepole pines with stain, cracks, borer holes, and wood decay are shown in Tables 11 and 12 and Figure 5.

Table 11. Percent fire-killed lodgepole pines with stain, cracks, borer holes, and decay by years since death.

Wood Change	Year 1	Year 2	Year 3	Year 4	Year 5
Stain	100	100	100	100	100
Cracks	55	100	100	100	100
Borer holes	15	35	30	45	35
Decay	10	30	15	30	15

Table 12. Percent wood volume affected by stain, cracks, and decay in fire-killed lodgepole pines by years since death.

Wood Change	Year 1	Year 2	Year 3	Year 4	Year 5
Stain	36.2	41.3	53.8	49.6	47.2
Cracks	10.0	47.0	62.4	65.2	64.8
Decay	0.01	0.06	0.0	0.09	0.1

Wood Changes in Fire-killed Lodgepole pine

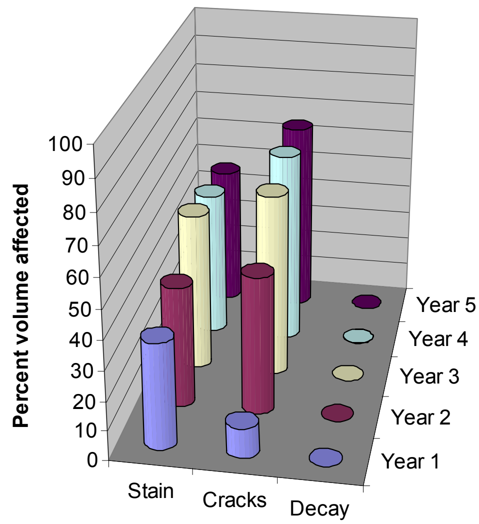


Fig. 5. Volume of wood of fire-killed lodgepole pine affected by stain, cracks, and decay by years since death.

Sapwood stain: All lodgepole pines sampled the first year had sapwood stain and more than 90 percent of the disks had stain. Almost all the sapwood was stained blue. At the end of one year, lodgepole pines had the highest percentage of volume stained of all tree species monitored. Even though every tree was stained early, the volume of wood stained increased up to year three, by which time all the sapwood was stained. Most of the stain was associated with bark beetle and wood borer attacks and cracks. Very little stained wood became decayed after five years (Tables A.29 and A.30).

Cracks: Fifty five percent of the lodgepole pines sampled at one year had cracks in the disks. Cracking was most common in disk position 1 at one year because bark loss was greater at the base of the trees than from positions higher on the stems. At the end of year two, all sampled trees had cracks and the percentage of disks with cracks increased dramatically from year one. Average crack depth did not increase much after year one but the average deepest crack depth did increase every year. The percentage wood volume affected by cracking increased substantially in years two and three then stabilized (Tables A.31 and A.32).

Decay: Decay losses were very small in fire-killed lodgepole pines over the five years. The greatest incidence of decay in the disks occurred at year four when 7 percent had decay. Practically all decay found was in disk 1. Decay losses in lodgepole never exceeded 0.1 percent wood volume. No conks were found on lodgepole pines (Tables A.33 and A.34).

Wood borers: Wood borers did not severely infest fire-killed lodgepole pines. Only 30 percent of the trees sampled at the end of year one had been infested. There appeared to be more attacks in year two and very few afterwards. Most disks showed no holes. The average number of holes per disk was lower for lodgepole pine than the other tree species monitored (Table A.35).

Other insects: Pine engraver galleries were found on 26 trees, mountain pine beetle galleries were seen on 14 trees. All bark beetle galleries appeared to have been made in year one. Two trees had ambrosia beetle galleries.

Snag failures: Two fire-killed lodgepole pines in one plot fell or were pushed over in year two.

Bark loss: Fire-killed lodgepole pines lost bark from lower portions of the trees more quickly than from higher positions. About one third of the bark was missing from log position one at the end of three years. About 70 percent of the bark was retained on log positions 3 and 4 after five years.

Branch loss: Lodgepole pine did not experience much branch loss until year 5 when 55 percent of the trees had lost more than half the fine branches and 10 percent had lost more than half the coarse branches.

Woodpecker feeding: Woodpecker feeding was found on five trees over the five year study. Foraging consisted of very few marks on the trees.

Yearly summary highlights of changes in fire-killed lodgepole pine:

Year One: All trees had sapwood stain and most of the sapwood was bluestained. Almost half the volume was affected by cracks.
Year Two: All sapwood volume was bluestained. More than 60% of the wood was affected by cracks.
Year Three: All sapwood was stained and cracks were common.
Year Four: Most bark close to the ground was gone.
Year Five: Almost no volume was available for salvage due to staining and cracks. Decay volume was small and few snags broke.

Ponderosa pine

Percent fire-killed ponderosa pines with stain, cracks, borer holes, and wood decay are shown in Tables 13 and 14 and Figure 6.

Table 13. Percent fire-killed ponderosa pines with stain, cracks, borer holes, and decay by years since death.

Wood Change	Year 1	Year 2	Year 3	Year 4	Year 5
Stain	95	100	100	NC*	NC*
Cracks	10	55	95	100	100
Borer holes	60	95	95	NC*	NC*
Decay	10	35	65	82	100

*Not Calculable due to decay.

Table 14. Percent wood volume affected by stain, cracks, and decay in fire-killed ponderosa pines by years since death.

Wood Change	Year 1	Year 2	Year 3	Year 4	Year 5
Stain	24.3	48.7	75.4	--*	--*
Cracks	15.7	28.7	30.0	43.2	--*
Decay	0.2	1.0	2.4	20.0	76.1

*Not Calculable due to decay.

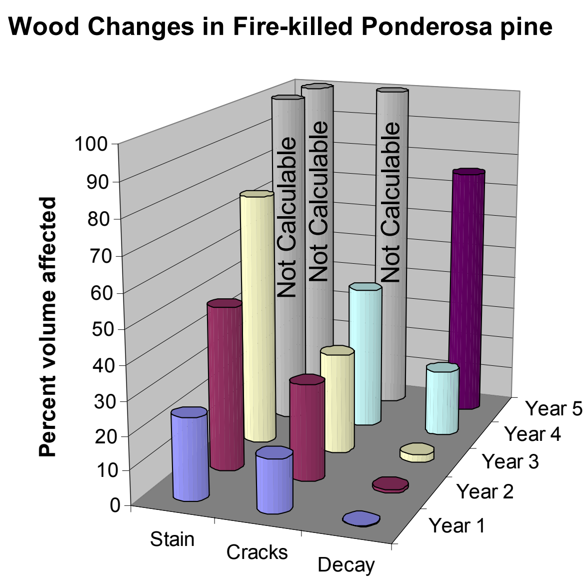


Fig. 6. Volume of wood of fire-killed ponderosa pines affected by stain, cracks, and decay by years since death.

Sapwood stain: Nineteen of the twenty fire-killed ponderosa pines sampled at the end of the first year had sapwood stain and three-quarters of the disks were stained. About 25 percent of the volume was stained by the end of the first year. Almost all the sapwood was stained blue. Even though every tree was stained early, the volume of wood stained increased up to year three, by which time all the sapwood was stained. At years four and five, the volume of wood stained decreased as wood previously stained became decayed (Tables A.36 and A.37).

Cracks: Fire-killed ponderosa pines had the lowest incidence of cracking of any species monitored at one year. At year three practically all the ponderosa pines had cracks. For the first three years, disk position 1 had low incidence of cracking then experienced a large increase in year four. Average crack depth did not change much over the first four years. The average deepest crack depth increased for each of the first three years. At year four many disks had decay that obscured cracks. Percent wood volume affected by cracking increased for the first four years then decreased substantially as wood containing cracks became decayed (Tables A.38 and A.39).

Decay: Wood decay developed quickly in fire-killed ponderosa pines. Pouch fungus conks were seen on three trees at the end of year one, and slightly less than half the trees at year two. Old pouch fungus conks were found at years three and four. Percent wood volume affected by decay was small for the first three years then increased substantially in year four as several trees broke due to extensive decay. Conks of the red rot fungus, (*Dichomitus squalens)* were found on two trees at year four and two trees at year five. More than three-quarters of the volume was affected by decay at the end of year five. Ponderosa pines decayed more rapidly and thoroughly than the other tree species studied (Tables A.40 and A.41).

Wood borers: Wood borers quickly infested fire-killed ponderosa pines. Three quarters of the trees sampled at year one had been infested and all trees sampled at the end of year two were infested. Disk position 1 had the highest incidence of attacks in each of the five years. The average number of holes per disk increased at positions 1, 2, and 3 each year. Several live borer larvae were seen in trees sampled at year 3 (Table A.42).

Other insects: Pine engraver (*Ips pini*) galleries were found on 46 trees. Western pine beetles (*Dendroctonus brevicomis*) and mountain pine beetles (*Dendroctonus ponderosae*) were found on 13 and 5 trees, respectively. Wood borers were so abundant in most trees they probably overran the bark beetle galleries or consumed the fresh phloem/cambium tissues before bark beetle larvae could.

Snag failures: In year three, four ponderosa pines broke and three had top breaks. In year four, eight trees broke and four had top breaks. In year five, seven trees broke and one had a top break. Ponderosa pine had the greatest rate of snag failures.

Bark loss: None of the ponderosa pines lost any bark after five years.

Branch loss: Ponderosa pines lost few branches the first three years, but at year four 53 percent lost more than half the fine branches and 23 percent lost more than half their coarse branches.

Woodpecker feeding: Woodpeckers foraged on ponderosa pines for at least the first three years, by which time all trees had feeding marks. Woodpecker foraging marks were abundant.

Yearly summary of highlights of changes in fire-killed ponderosa pine:

Year One: Almost all trees had sapwood bluestained. Most trees were infested by wood borers and many had been foraged on by woodpeckers.

Year Two: All sapwood volume was bluestained. All trees had been infested by wood borers and most had been fed on by woodpeckers. About 30% of the volume was affected by cracks. About half the trees had pouch fungus conks but decay volume was small.

Year Three: Trees began to break from decay.

Year Four: Many trees broke from decay. Most of the sapwood was decayed.

Year Five: Very little volume was available for salvage. More than 75% of the volume was decayed. Many trees were broken.

Engelmann spruce

Percent fire-killed Engelmann spruce with stain, cracks, borer holes, and wood decay are shown in Tables 15 and 16 and Figure 7.

Table 15. Percent fire-killed Engelmann spruce with stain, cracks, borer holes, and decay by years since death.

Wood Change	Year 1	Year 2	Year 3	Year 4	Year 5
Stain	100	100	100	100	100
Cracks	65	100	100	100	100
Borer holes	5	50	60	60	74
Decay	5	30	25	35	47

Table 16. Percent wood volume affected by stain, cracks, and decay in fire-killed Engelmann spruce by years since death.

Wood Change	Year 1	Year 2	Year 3	Year 4	Year 5
Stain	12.9	20.4	19.3	23.5	30.7
Cracks	34.5	38.5	44.8	53.4	57.1
Decay	0.0	0.04	0.1	0.1	3.6

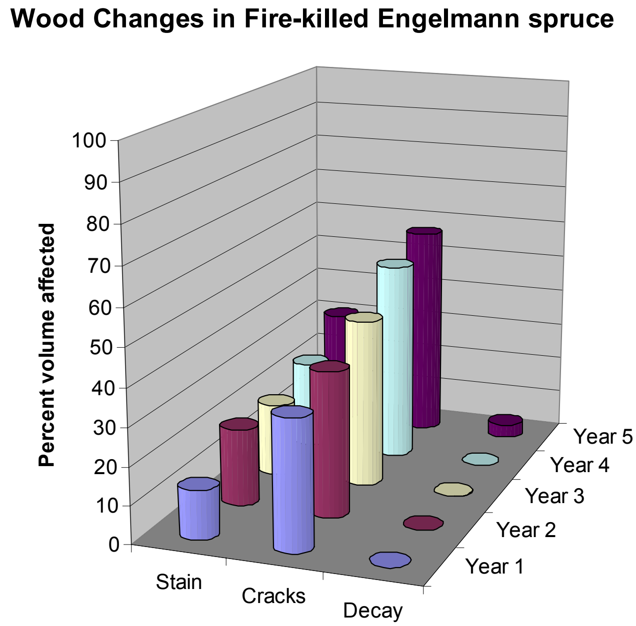


Fig. 7. Volume of wood of fire-killed Engelmann spruce affected by stain, cracks, and decay by years since death.

Sapwood stain: Every Engelmann spruce sampled at the end of the first year had sapwood stain and slightly over half the disks collected had stain. Disks collected from the 4-inch tops had the lowest incidence of stain. Staining was strongly associated with attacks by ambrosia beetles on three of the four spruce plots. Log position 1 had the highest percent wood volume stained due the preponderance of ambrosia beetle attacks occurring in the lower portions of the boles. The percent volume of wood stained increased in year two and then remained stable until another increase in year five (Tables A.43 and A.44).

Cracks: Sixty five percent of the fire-killed Engelmann spruce had cracked disks after the trees had been dead for one year. Position one disks from the stumps had the highest incidence of cracking. Bark loss was greater from the base of the trees than from locations higher on the stems at the end of year one. By the end of year two all sampled trees had cracks and a high percentage of the disks were cracked. Average crack depth did not change much over five years, but the average deepest crack depth increased at almost every position each year. Few disks were cracked to their centers. More than a third of the wood volume was affected by cracking at the end of one year, remained almost the same in year two and then increased in years three and four. After five years many disks had spots of decay associated with the cracks (Tables A.45 and A.46).

Decay: No decay was found in Engelmann spruce disks after one year. Decay was found in 30 percent of the disks from position 1 at year two and the incidence did not change much over the next three years. Most spots of decay were in disk position 1. Wood volume affected by decay was less than 1 percent for the first four years then increased to

3.6 percent in year five as decay spots became larger in the disk 1 positions. Most of the decay appeared to be associated with cracks. Only one spruce had a conk, the pouch fungus (Tables A.47 and A.48).

Wood borers: Fire-killed Engelmann spruces were not severely infested by wood borers. Most disks did not have borer holes. Many borer attacks apparently did not result in holes in the wood. There appeared to be an increase in borer attacks and number of holes in year 5 for disk positions 1 and 2. Depth of borer holes stayed relatively unchanged for the first four years then increased in year five for position 1 (Table A.49).

Other insects: Ambrosia beetle galleries were found on 69 trees, more than any other tree species. Ips galleries were seen on three trees.

Snag failures: One fire-killed spruce broke and one had a broken top at year two. In year three, one tree was pushed over. One tree fell in year four and two trees had top breaks in year five.

Bark loss: Fire-killed Engelmann spruces lost bark most quickly from the lower portions of the trees. At the end of three years, 60 percent of the bark was missing from log position 1 but about 70 percent was retained on log positions 3 and 4. Bark loss continued the next two years, so at the end of five years only one third of the bark was retained on log position 1 and about 60 percent was still retained on log positions 3 and 4.

Branch loss: Engelmann spruces lost fine branches quickly. At the end of three years, 35 percent of the trees had lost more than half their fines. After five years, 58 percent had lost more than half the coarse branches.

Woodpecker feeding: Very few fire-killed Engelmann spruces were foraged on by woodpeckers. Trees foraged on by woodpeckers had very few scattered feeding marks.

Yearly summary highlights of changes in fire-killed Engelmann spruce.:

Year One: Many trees had sapwood stain associated with ambrosia beetle attacks. About 1/3 of the volume was affected by cracks which were most common close to the ground.

Year Two: Almost 20% of the volume was affected by sapwood stain and almost 40% of the volume was affected by cracks.

Year Three: Almost 60% of the bark was gone from the basal logs and about 45% of the volume was affected by cracks.

Year Four: More than half the volume was affected by cracks.

Year Five: Cracks affected more than half the volume. Decay volume was small and strongly associated with cracks in the basal portions of the trees. Tops began to break in year five.

Discussion:

Trees killed outright by 1994 wildfires in eastern Washington experienced many changes over five years. Changes began quickly after tree death. Changes were predominantly brought about by insects, fungi, and weather, often working in concert. Many changes were progressive, with some agents setting the stage for other agents that affected the trees later.

Other studies of fire-killed trees found wood changes were influenced by a large number of factors, including tree species, tree size, rate of growth, burn severity, and site characteristics (1,2,5,7,15,16,19,20,21,22,23). That was also the case with fire-killed trees in eastern Washington. There were major differences between the seven tree species in how they changed over the five years since death. Patterns of changes over the five years were apparent for the seven tree species.

Wildfires directly affected the fire-killed trees by scorching and in many cases consuming foliage, cooking phloem/cambium tissues, scorching and in a few cases consuming bark, and in very few cases burning wood.

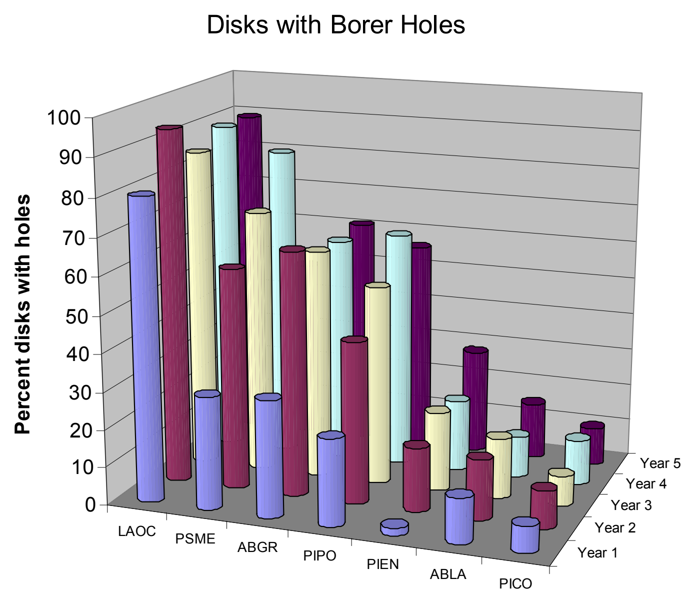
Less than one percent of the wood volume in the sampled trees was charred. Other investigators reported losses of wood directly to fire typically are less than four percent of the merchantable volume (2,15,16,19,23). Much of the charred wood found in this study was associated with old, bark removing injuries predating the 1994 fires. Thin bark species had more instances of char than thick bark species. Most spots of char were close to the ground.

Fire-killed trees were rapidly infested by several species of insects, subalpine fir being the only exception. Thick bark tree species experienced more insect attacks than thin-bark species. Insects brought about many changes in the fire-killed trees.

Wood borers were important agents of change in several tree species. All tree species were infested by borers but thick bark species had more attacks than thin bark species. Figure 8 illustrates the differences in wood borer attacks over five years for the seven tree species. Some species of wood borers are attracted to heat sources, including burning and smoldering trees (6, 18). Thick bark tree species, including Douglas-fir, western larch, ponderosa pines, and some large diameter grand firs appeared to have been abundantly infested by wood borers in the same season as the fire occurrence. Richmond and Lejeune (22) reported that some species of wood-boring insects infested fire-killed white spruce the same season fire killed the trees. The thick bark trees typically had phloem/cambium tissues sufficiently fresh to support broods of wood boring larvae. Thin bark tree species, including subalpine fir, lodgepole pine, and Engelmann spruce had fewer attacks by wood borers than did the thick bark species. Wood borers initiated several changes in fire-killed trees. The larvae fed on phloem/cambium tissues and loosened the bond between bark and wood. Trees with loose bark developed cracks.

Trees with wood borers almost always had stain caused by fungi. Presumably some spores and mycelial fragments were deposited from adults mating and laying eggs in bark and crevices. Western larch has almost no bark beetles that successfully infest the species and in this study almost all the larches sampled at the end of one year had large populations of wood borers and all had stain in the sapwood. Wood borers make tunnels in the wood. Tunnels extended several inches into the wood in many trees and frequently became foci of wood decay. Trees with abundant wood borer populations were actively foraged by woodpeckers, creating holes 0.5 to 1.0 inch deep into the wood to extract the larvae. Foraging holes made by woodpeckers contributed to cracking and decay as the exposed wood dried and was exposed to fungal spores. Most wood borer attacks took place in the first year when the phloem/cambium tissues were still suitable to support species that require such tissues for development of early larvae. Wood borers continued to infest Douglas-fir and ponderosa pines with thick bark through the third year but there appeared to be few attacks on the thin bark species and thin bark sections of thick bark species after the first year. Another group of wood borers began to infest the fire-killed trees after sapwood decay became well established in the trees. Furniss (7) reported ponderous wood borers infested fire-killed Douglas-firs 5 to 8 years after the trees had been killed.

Figure 8. Percent of disks with wood borer holes by tree species by years since death.



Most bark beetle species in eastern Washington infest trees in the spring and early summer. Most large wildfires in this area occur from July through September. Most bark beetle attacks on fire-killed trees in the study plots in eastern Washington took place in the spring and summer 9 to 12 months after the fires. Fir engravers were an exception. Fully completed fir engraver larval galleries and emergence holes were found on many grand firs sampled one year after they had been killed. In large numbers of thick bark trees, wood borers occupied the phloem/cambium tissues before bark beetles. This probably reduced the success of many bark beetle broods by depriving bark beetle larvae of adequate food. It is unlikely that bark beetles infested fire-killed trees after they had been dead for more than a year because the phloem/cambium tissues were fermented or dry and were no longer suitable for larval development. Bark beetles introduced stain and decay fungi into fire-killed trees when they made boring holes and egg galleries. The feeding action of bark beetle larvae loosened the bond between bark and wood. There appeared to be little woodpecker feeding on bark beetles in the study trees; they concentrated on the wood borers.

Bark beetles are major vectors of the pouch fungus, *Cryptoporus volvatus*. A high percentage of fire-killed Douglas-firs had conks of the pouch fungus. Douglas-fir beetle is the primary vector of the pouch fungus to Douglas-fir trees (3, 4), but very few successfully completed Douglas-fir beetle galleries were found in the study trees. It appeared that Douglas-fir beetles made entrance holes and egg laying galleries in the fire-killed trees and in the process inoculated them with the pouch fungus. Douglas-fir beetles also transport spores and mycelial fragments of *Fomitopsis pinicola*, the red belt fungus, one of the most common saprophytes on dead Douglas-firs (3,4). A similar situation occurred in ponderosa pines with western pine beetles and mountain pine beetles inoculating the trees with the pouch fungus. Few completed western pine beetle and mountain pine beetle galleries were found in fire-killed ponderosa pines because wood borer galleries were so abundant in the phloem/cambium tissues. Fir engravers inoculated several of the fire-killed grand firs with the pouch fungus.

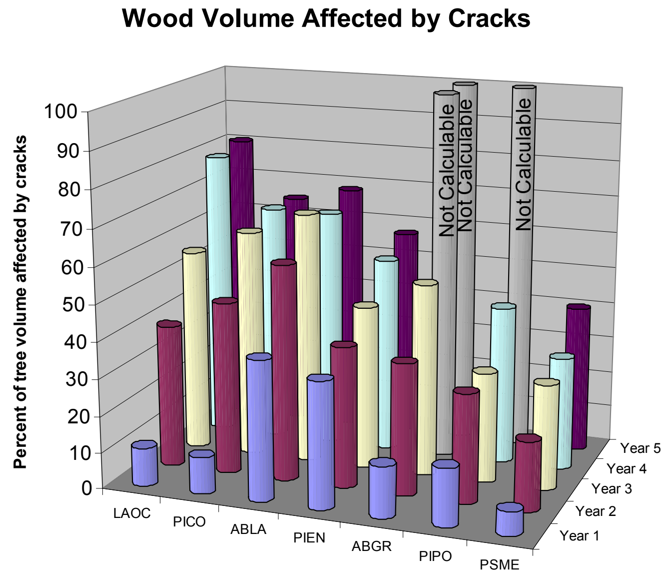
Ambrosia beetle tunnels were found in all seven tree species. In the fall of 1994, very few ambrosia beetle attacks were observed on trees as plots were established. Most ambrosia beetle attacks took place in the spring and summer of 1995, with some additional attacks in 1996. Engelmann spruce was subject to more ambrosia beetle attacks than other species. Ambrosia beetles excavated small diameter tunnels in wood of infested trees. In Engelmann spruce the tunnels extended as far as three inches into the wood one year after the trees had been fire killed. The perimeter of the tunnels was stained black to dark purple from species of fungi carried by the adults and used to feed the larvae. Very few ambrosia beetle tunnels were the introduction sites of wood decay.

Weather was a major agent of change in fire-killed trees in eastern Washington. This is in contrast with some studies involving deterioration of fire-killed trees in western Washington, Oregon and northern California (2,15,16). However, Lowell and Cahill (19) working with fire-killed Douglas-fir, true firs, ponderosa pine and sugar pine in the coastal mountains of southern Oregon and northern California did report weather checking as causing significant losses. The eastern Washington forests burned in the 1994 fires are typically dry, with a high percent of annual precipitation occurring as snow. Summers are dry and generally hot. Weather was mostly responsible for cracks in the trees and loss of bark and branches in many.

It was not possible to determine in this study if some fire-killed trees were cracked directly from heat from the fires.

The hot air temperatures and low relative humidities common at the sites caused wood in the dead trees to shrink and crack. Trees on the driest, hottest sites cracked before those on moister, cooler sites. Thin bark species and thin bark portions of thick bark trees cracked more quickly than thick bark species. Figure 9 illustrates the differences in wood volume affected by cracking between the seven tree species. Disks from position 1 from thin bark species were likely to be cracked more quickly than higher position disks. Just the opposite occurred on Douglas-fir, grand fir, and ponderosa pine with the lowest disk position being least likely to be cracked in the first two years. The south sides of fire-killed grand firs developed cracks before the north sides. Thick bark delayed cracking by one year. Trees with thick bark that had bark loosened by wood borers and bark beetles developed cracks even though almost no bark sloughed from the trees.

Figure 9. Wood volume affected by cracks in fire-killed trees by tree species by years since death.

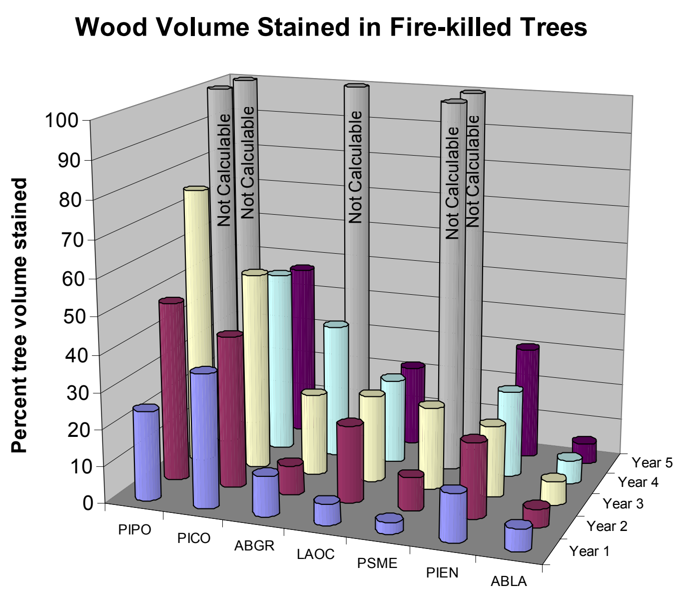


Cracks brought about other changes. Cracks in large diameter portions of trees contributed to stain and decay. Cracks in small diameter portions of trees caused the trees to lose moisture from the wood making it less suitable for infestation by insects and colonization by fungi. Very few borer holes and little decay were found in many of the deeply cracked upper logs and disks collected from standing trees. Large percentages of wood volume were affected by cracking in several species.

Snow appeared to bring about changes in the fire-killed trees. Bark below the snow level on thin bark species (grand fir, subalpine fir, lodgepole pine, and Engelmann spruce) was lost more rapidly than bark above the snow. Removal of bark by snow contributed to quicker formation of cracks. Snow, and probably ice, also removed branches from the dead trees.

Fungi were major agents of change in fire-killed trees. Insects and fungi were closely associated. Insects were responsible for inoculating many trees with stain and decay fungi. Cracks in the wood also served as colonization foci for fungi. Fungi caused stain and decay in the fire-killed trees. Stain caused by fungi appeared quickly. Most trees sampled at the end of one year had sapwood stain. Most of the stain was introduced by bark beetles, but some stain seemed to be introduced by wood borers. All western larch sampled at year one were abundantly infested by wood borers and 80 percent of the disks had borer galleries. Very few bark beetle species infest larch. Nineteen of 20 larch had stain at the end of year one. Most stain in larch was associated with wood borer infestations. Some sapwood stain in the other tree species also appeared to be due to borer infestations. Stain was confined to sapwood in all tree species. The sapwood of lodgepole pine and ponderosa pine was almost completely bluestained after one year. Stain in the other tree species typically appeared as unconnected spots in the sapwood in year one. Stain fungi continued to spread in the sapwood of the non-pine species in years two and three until most of the sapwood was stained or the wood became too dry to support fungal growth. Figure 10 illustrates differences in wood volumes affected by staining between the seen tree species.

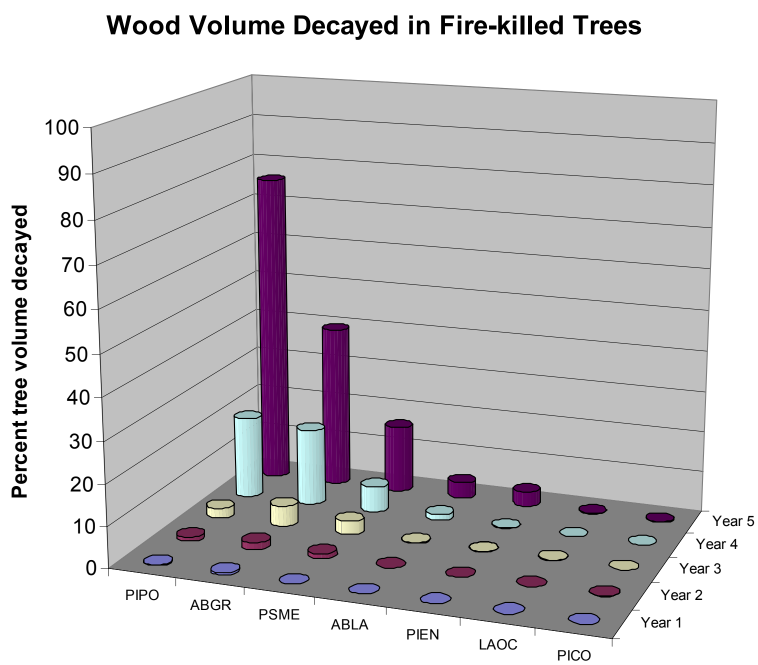
Figure 10. Wood volume affected by stain in fire-killed trees by tree species by years since death.



The pouch fungus appeared to loosen the bark on many colonized trees. Thick white mycelium occupied the position of phloem/cambium tissues and several pouch fungus conks protruded from bark beetle holes. It appeared the pouch fungus grew very quickly in the moist, sugar rich phloem/cambium tissues but there was almost no detectable decay in the adjacent xylem at the end of year two, even though there were large numbers of conks on the trees.

Fire-killed trees in eastern Washington experienced little wood volume loss from decay in year one, a pattern reported in other studies (1,2,15,16,19,20,23). Many trees were inoculated with decay fungi in year one, especially by bark beetles carrying spores and mycelial fragments. The first decay fungus to appear in fire-killed trees was the pouch fungus. A few ponderosa pines and grand firs sampled at the end of year one had pouch fungus conks, meaning they had been inoculated in 1994, the year of the fires. Large numbers of Douglas-firs, ponderosa pines, and grand firs had pouch fungus conks at the end of year two, resulting from inoculations in 1995. Volume of wood affected by decay increased slightly in year two and three but was still small for all tree species. Spots of decay were apparent in several ponderosa pines and grand firs at year two. A few ponderosa pines broke from decay between years two and three. Sapwood decay became common in many Douglas-firs in year three. Conks of *F. pinicola* were seen on Douglas-firs in year three. This decay fungus was suspected to be the cause of brown rot in many trees. Volume of wood decayed increased substantially in year four in Douglas-fir, grand fir, and ponderosa pine. Grand fir and ponderosa pine experienced large increases in decay in year four and several trees broke because so much wood was decayed. Small diameter trees tended to break before large diameter trees, similar to results reported by others (5,20,21). Figure 11 illustrates the differences in wood volumes affected by decay over the five years for the seven tree species.

Figure 11. Wood volume affected by decay in fire-killed trees by tree species by years since death.



Subalpine fir, western larch, lodgepole pine, and Engelmann spruce experienced small losses to decay over the five year period. Many trees appeared to be too dry to support growth of decay fungi, especially in the upper portions. Most of these trees had deep cracks exacerbating moisture loss. Even in grand fir, decay was mainly limited to the lowest two disk positions. With the notable exception of western larch, thin-bark species had less decay for the five year period than the thick-bark species. Everett et. al. (7) found thin bark species stood as snags longer than thick bark species in eastern Washington. Ponderosa pine had substantial decay, and lost 76% of its volume to decay by the end of year 5. An on-going investigation of fire-killed western larch in northwestern Montana has found more decay than was found in eastern Washington larch Jackson and Bulaon, (14). The Montana study found sapwood decay in some trees two years after they died and large increases in the third and fourth years. *F. pinicola* conks were found on many of the Montana trees but were never seen on the eastern Washington trees.

Trees that had the largest number of attacks by wood borers and bark beetles tended to decay fastest, with the notable exception of western larch which had almost no decay after five years. Many stem breaks occurred in the lowest two logs, which tended to have the highest percentage of disks with insect attacks. In Douglas-fir and ponderosa pine there appeared to be an association between increases in decay in the disks and an increase in the number of borer holes. Beal, et. al. 1935 (2) and Furniss, 1937 (8) reported that the ponderous wood borer (*Ergates spiculatus)* infested fire-killed Douglas-firs five to eight years after the trees had been killed, well after the sapwood was decayed.

Much stained wood became decayed as decay fungi replaced stain fungi. Grand fir and ponderosa pine sapwood in the lowest log was almost all decayed by year four. Douglas-fir sapwood in the lowest logs was almost all decayed by year five. Sections of trees that broke and were lying on the ground were almost 100 percent decayed.

Wood decay spread from the roots and root collars up into the stems of grand fir, subalpine fir, lodgepole pine, and Engelmann spruce, the upper parts of which were too dry to enable decay fungi to grow.

There were substantial differences in the timing and frequency of snag breaks between the seven tree species. Ponderosa pine which has a high percentage of it wood volume in sapwood rather than heartwood decayed most rapidly and experienced stem breakage quickly. It was closely followed by grand fir. In general the thick-bark species broke more quickly than thin-bark species with the notable exception of western larch. The thin-bark species, subalpine fir, Engelmann spruce, and lodgepole pine had low incidence of insect attacks and they cracked very quickly and appeared to be too dry for decay fungi to grow.

References:

1. Basham, J.T. 1957. The deterioration by fungi of jack, red, and white pine killed by fire in Ontario. Canadian Journal of Botany. 35: 155-172.

2. Beal, J.A.; Kimmey, J.W.; Rapraeger, E.F. 1935. Deterioration of fire-killed Douglas-fir. The Timberman. 37(2): 12-17.

3. Borden, J.H.; McClaren, M. 1970. Biology of *Cryptoporus volvatus* (Peck) Shear (Agaricales, Polyporaceae) in southwestern British Columbia: distribution, host species, and relationship with subcortical insects. Syesis. 3: 145-154.

4. Castello, J.D.; Shaw, C.G.; Furniss, M.M. 1976. Isolation of *Cryptoporus volvatus* and *Fomes pinicola* from *Dendrontonus pseudotsugae*. Phytopathology. 66: 14311434.

5. Dahms, W.G. 1949. How long do ponderosa pine snags stand? Research Notes No. 57. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 3 p.

6. Evans, W.G. 1966. Perception of infrared radiation from forest fires by *Melanophila acuminata* De Geer (Buprestidae, Coleoptera). Ecology. 47(6): 1061-1065.

7. Everett, R.; Lehmkuhl, J.;Schellhaas, R.; Ohlson, P.; Keenum, D.;Riesterer, H.; Spurbeck, D. 1999. Snag dynamics in a chronosequence of 26 wildfires on the east slope of the Cascade Range in Washington State, USA. International Journal of Wildland Fire. 9(4): 223-234.

8. Furniss, R.L. 1937. Salvage on Tillimook Burn as affected by insect activity. The Timberman. December: 11-13, 30-32.

9. Hadfield, J.S., Magelssen, R.M. 1996. Wood changes in fire-killed Eastern Washington tree species—first year progress report. USDA-Forest Service, Wenatchee National Forest, Wenatchee, WA. 25p.

10.___. 1997. Wood changes in fire-killed Eastern Washington tree species—year two progress report. USDA-Forest Service, Wenatchee National Forest, Wenatchee, WA. 34p.

11.___. 1998. Wood changes in fire-killed Eastern Washington tree species—year three progress report. USDA-Forest Service, Wenatchee National Forest, Wenatchee, WA. 37p.

12___. 1999. Wood changes in fire-killed Eastern Washington tree species—year four progress report. USDA-Forest Service, Wenatchee National Forest, Wenatchee, WA. 35p.

13.___ 2000. Wood changes in fire-killed Eastern Washington tree species—year five progress report. USDA-Forest Service, Wenatchee National Forest, Wenatchee, WA. 34p.

14. Jackson, M., Bulaon, B. 2005. Changes in fire-killed western larch on the Glacier View Ranger District (Flathead National Forest, Montana. Years two, three, and four report. Forest Health Protection, Numbered Report 05-06. USDA-Forest Service Northern Region, Missoula, MT. 20p.

15. Kimmey, J.W.; Furniss, R.L. 1943. Deterioration of fire-killed Douglas-fir. Tech. Bull. 851. Washington, DC: U.S. Department of Agriculture. 61 p.

16. Kimmey, J.W. 1955. Rate of deterioration of fire-killed timber in California. Circular 962. Washington, DC: U.S. Department of Agriculture. 22 p.

17. Knapp, J.B. 1912. Fire-killed Douglas-fir: a study of its rate of deterioration, usability and strength. Bull. 112. Washington, DC: U.S. Department of Agriculture, Forest Service. 18 p.

18. Linsley, E.G. 1943. Attraction of Melanophila beetles by fire and smoke. J. Econ. Entomol. 36: 341-342.

19. Lowell, E.C.; Cahill, J.M. 1996. Deterioration of fire-killed timber in southern Oregon and northern California. Western Journal of Applied Forestry. 11(4): 125-131.

20. Lyon, L.J. 1977. Attrition of lodgepole pine snags on the Sleeping Child Burn, Montana. Research Note INT-219. Ogden,UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 4 p.

21. Raphael, M.G.;Morrison, M.L. 1987. Decay and dynamics of snags in the Sierra Nevada, California. Forest Science. 33(3): 774-783.

22. Richmond, H.A.; Lejeune, R.R. 1945. The deterioration of fire-killed white spruce by wood boring insects in northern Saskatchewan. Forestry Chronicles. 21: 168-192.

23. Wallis, G.W.; Godfrey, J.N.; Richmond, H.A. 1974. Losses in fire-killed timber. Victoria, BC: Pacific Forest Research Center. 11 p.

Appendices:

Douglas-fir tables

Table A.1. Percent disks with stain from fire-killed Douglas-firs.

Disk position	Year 1	Year 2	Year 3	Year 4	Year 5
1	50	88	100	90	53
2	65	96	100	90	68
3	54	88	100	100	74
4	31	84	96	95	68
5	15	60	76	60	63
All disks	40	83	94	87	86

Table A.2. Percent average log and tree volume with stain from fire-killed Douglas-firs.

	Year 1	Year 2	Year 3	Year 4	Year 5
Log 1	2.4	7.6	18.7	15.4	8.5
Log 2	3.3	9.3	22.9	16.1	14.5
Log 3	4.5	10.7	26.4	21.7	14.4
Log 4	2.5	12.2	29.9	27.3	16.8
Tree	3.1	9.0	22.4	17.7	12.0

Table A.3. Percent disks with cracks from fire-killed Douglas-firs.

Disk Position	Year 1	Year 2	3 Year	Year 4	Year 5
1	4	8	16	10	32
2	12	44	56	85	68
3	31	64	76	90	74
4	23	72	92	75	58
5	15	72	68	75	58
All disks	17	52	62	67	76

Table A.4. Percent average calculated log and tree volume affected by cracks from fire-killed Douglas-firs.

	Year 1	Year 2	Year 3	Year 4	Year 5
Log 1	3.0	6.5	12.1	12.2	23.8
Log 2	7.0	24.2	33.6	45.1	57.3
Log 3	11.0	31.6	47.3	46.0	50.9
Log 4	12.8	39.4	51.2	48.8	44.6
Tree	6.5	19.0	28.8	30.9	40.3

Table A.5. Percent disks with decay from fire-killed Douglas-firs.

Disk Position	Year 1	Year 2	Year 3	Year 4	Year 5
1	0	20	36	80	79
2	0	36	52	60	37
3	0	28	24	40	47
4	0	8	16	35	53
5	0	4	0	15	42
All disks	0	19	26	46	52

Table A.6. Percent average log and tree volume with decay from fire-killed Douglas-firs.

	Year 1	Year 2	Year 3	Year 4	Year 5
Log 1	0	0.8	3.0	8.3	16.6
Log 2	0	1.7	4.8	5.8	14.9
Log 3	0	0.8	3.3	3.4	17.2
Log 4	0	0.9	0.8	5.0	18.2
Tree	0	1.1	3.3	6.4	16.4

Table A.7. Percent disks with wood borer holes from fire-killed Douglas-firs.

Disk Position	Year 1	Year 2	Year 3	Year 4	Year 5
1	42	64	96	90	68
2	35	64	84	95	53
3	35	76	72	95	58
4	27	64	68	85	42
5	12	28	28	50	21
All disks	15	59	70	83	50

Grand fir tables:

Table A.8. Percent disks with stain from fire-killed grand firs.

Disk position	Year 1	Year 2	Year 3	Year 4	Year 5
1	100	88	100	78	61
2	96	84	96	96	61
3	88	88	100	100	61
4	76	84	100	87	61
5	52	48	64	78	30
All disks	79	81	92	88	86

Table A.9. Percent average log and tree volume with stain from fire-killed grand firs.

	Year 1	Year 2	Year 3	Year 4	Year 5
Log 1	11.1	5.5	13.6	25.6	9.8
Log 2	11.6	8.5	22.1	45.5	10.5
Log 3	9.8	12.2	37.8	46.1	10.0
Log 4	9.2	10.3	30.3	41.3	3.9
Tree	10.9	8.0	22.2	36.6	9.5

Table A.10. Percent disks with cracks from fire-killed grand firs.

Disk Position	Year 1	Year 2	Year 3	Year 4	Year 5
1	40	68	88	70	30
2	52	88	92	91	65
3	56	96	96	100	61
4	60	84	100	87	65
5	40	92	96	91	57
All disks	50	86	94	88	86

Table A.11. Percent average calculated log and tree volume affected by cracks from fire-killed grand firs.

	Year 1	Year 2	Year 3	Year 4	Year 5
Log 1	8.2	19.5	34.4	30.0	16.4
Log 2	14.8	42.6	59.5	63.0	38.1
Log 3	21.6	54.8	69.8	64.8	43.1
Log 4	25.1	60.9	78.8	67.8	47.6
Tree	14.0	35.9	52.5	49.6	30.4

Table A.12. Percent disks with decay from fire-killed grand firs.

Disk Position	Year 1	Year 2	Year 3	Year 4	Year 5
1	56	72	84	83	100
2	28	36	32	61	57
3	4	24	16	30	48
4	0	8	4	35	57
5	0	4	0	17	39
All disks	18	29	27	45	61

Table A.13. Percent average log and tree volume with decay from fire-killed grand firs.

	Year 1	Year 2	Year 3	Year 4	Year 5
Log 1	0.8	2.9	10.6	277.3	45.0
Log 2	0.3	0.9	1.8	13.0	35.9
Log 3	0.03	0.9	0.3	10.9	35.2
Log 4	0.0	0.3	0.1	13.6	37.3
Tree	0.4	1.8	5.0	18.8	39.8

Table A.14. Percent disks with wood borer holes from fire-killed grand firs.

Disk Position	Year 1	Year 2	Year 3	Year 4	Year 5
1	20	48	52	70	52
2	44	6	52	74	48
3	48	64	72	61	52
4	28	52	56	48	30
5	0	12	24	13	26
All disks	31	65	61	60	61

Subalpine fir tables:

Table A.15. Percent disks with stain from fire-killed subalpine firs.

Disk position	Year 1	Year 2	Year 3	Year 4	Year 5
1	75	100	90	95	86
2	85	100	100	95	76
3	80	90	95	95	81
4	70	75	90	85	71
5	35	70	60	50	71
All disks	69	87	87	84	77

Table A.16. Percent average log and tree volume with stain from fire-killed subalpine firs.

	Year 1	Year 2	Year 3	Year 4	Year 5
Log 1	6.8	5.2	4.3	6.2	5.8
Log 2	5.2	4.9	6.8	6.6	5.5
Log 3	5.5	4.4	8.9	7.0	5.3
Log 4	6.0	4.9	9.5	6.4	4.8
Tree	6.0	4.9	6.3	6.4	5.5

Table A.17. Percent disks with cracks from fire-killed subalpine firs.

Disk Position	Year 1	Year 2	Year 3	Year 4	Year 5
1	95	100	100	100	100
2	80	95	100	100	100
3	80	95	100	100	100
4	85	95	100	100	100
5	55	65	85	95	100
All disks	79	90	97	99	100

Table A.18. Percent average calculated log and tree volume affected by cracks from fire-killed subalpine firs.

	Year 1	Year 2	Year 3	Year 4	Year 5
Log 1	36.0	51.5	59.3	56.4	60.1
Log 2	37.9	62.5	72.8	69.5	71.1
Log 3	42.5	71.1	81.5	74.7	75.6
Log 4	44.3	60.6	74.5	77.1	78.5
Tree	38.3	59.0	68.7	65.2	68.4

Table A.19. Percent disks with decay from fire-killed subalpine firs.

Disk Position	Year 1	Year 2	Year 3	Year 4	Year 5
1	5	15	10	30	76
2	0	0	0	15	33
3	0	5	0	15	24
4	0	0	0	5	5
5	0	0	0	0	5
All disks	1	4	2	13	28

Table A.20. Percent average log and tree volume with decay from fire-killed subalpine firs.

	Year 1	Year 2	Year 3	Year	Year 5
Log 1	0	0	0	2.0	6.0
Log 2	0	0	0	0.6	4.2
Log 3	0	0	0	1.2	1.4
Log 4	0	0	0	0.8	0
Tree	0	0	0.1	1.4	4.0

Table A.21. Percent disks with wood borer holes from fire-killed subalpine firs.

Disk Position	Year 1	Year 2	Year 3	Year 4	Year 5
1	25	15	15	30	24
2	15	20	0	10	14
3	10	25	5	5	19
4	10	10	0	5	10
5	0	10	10	5	10
All disks	12	16	6	11	15

Western larch tables:

Table A.22. Percent disks with stain from fire-killed western larch.

Disk position	Year 1	Year 2	Year 3	Year 4	Year 5
1	85	95	100	100	100
2	95	100	100	93	100
3	85	100	95	79	87
4	75	95	95	79	80
5	50	75	75	50	67
All disks	77	93	93	80	87

Table A.23. Percent average log and tree volume with stain from fire-killed western larches.

	Year 1	Year 2	Year 3	Year 4	Year 5
Log 1	4.9	14.8	24.8	25.9	21.2
Log 2	6.9	28.3	25.4	23.0	23.9
Log 3	5.7	25.4	22.4	19.4	21.8
Log 4	5.4	19.0	17.6	19.9	20.3
Tree	5.7	20.9	23.7	23.1	21.9

Table A.24. Percent disks with cracks from fire-killed western larches.

Disk Position	Year 1	Year 2	Year 3	Year 4	Year 5
1	60	80	80	100	100
2	50	90	85	100	100
3	50	90	95	93	100
4	40	90	90	100	100
5	25	90	75	100	100
All disks	45	88	85	99	96

Table A.25. Percent average calculated log and tree volume affected by cracks in fire-killed western larches.

	Year 1	Year 2	Year 3	Year 4	Year 5
Log 1	8.9	28.8	42.9	70.2	75.2
Log 2	11.5	42.4	58.5	81.9	82.1
Log 3	12.9	48.1	72.9	85.3	83.4
Log 4	11.5	58.0	64.7	89.4	91.7
Tree	10.5	39.1	55.4	78.6	80.3

Table A.26. Percent disks with decay from fire-killed western larches.

Disk Position	Year 1	Year 2	Year 3	Year 4	Year 5
1	5	0	10	0	13
2	0	0	5	0	0
3	0	0	5	0	7
4	0	0	0	7	0
5	5	0	0	0	0
All disks	1	0	4	1	4

Table A.27. Percent average log and tree volume with decay from fire-killed western larches.

	Year 1	Year 2	Year 3	Year 4	Year 5
Log 1	0	0	0.3	0	0.1
Log 2	0	0	0.2	0	0.2
Log 3	0	0	0.2	0.02	0.3
Log 4	0.03	0	0	0.03	0
Tree	0	0	0.2	0.01	0.2

Table A.28. Percent disks with wood borer holes from fire-killed western larches.

Disk Position	Year 1	Year 2	Year 3	Year 4	Year 5
1	95	100	95	100	100
2	95	95	95	86	100
3	95	95	95	93	100
4	90	95	95	93	93
5	25	85	45	71	53
All disks	80	94	85	89	89

Lodgepole pine tables:

Table A.29. Percent disks with stain from fire-killed lodgepole pines.

Disk position	Year 1	Year 2	Year 3	Year 4	Year 5
1	100	100	100	100	100
2	100	100	100	100	100
3	95	95	100	100	100
4	90	95	100	100	100
5	70	85	90	95	100
All disks	91	90	100	99	100

Table A.30. Percent average log and tree volume with stain from fire-killed lodgepole pines.

	Year 1	Year 2	Year 3	Year 4	Year 5
Log 1	40.0	40.4	50.7	46.2	43.6
Log 2	32.1	38.2	51.4	46.0	44.0
Log 3	34.8	44.5	59.2	55.3	53.1
Log 4	33.9	48.1	62.9	63.9	58.9
Tree	36.2	41.3	53.8	49.6	47.2

Table A.31. Percent disks with cracks from fire-killed lodgepole pines.

Disk Position	Year 1	Year 2	Year 3	Year 4	Year 5
1	55	100	100	100	100
2	30	85	100	95	100
3	10	70	100	95	90
4	0	50	75	80	90
5	0	45	60	65	90
All disks	19	70	87	87	94

Table A.32. Percent average calculated log and tree volume affected by cracks in fire-killed lodgepole pines.

	Year 1	Year 2	Year 3	Year 4	Year 5
Log 1	17.2	47.6	56.1	56.7	60.2
Log 2	7.7	52.1	69.6	74.1	67.2
Log 3	1.3	43.9	69.4	74.3	66.4
Log 4	0	36.1	55.8	59.4	73.7
Tree	10.0	47.0	62.4	65.2	64.8

Table A.33. Percent disks with decay from fire-killed lodgepole pines.

Disk Position	Year 1	Year 2	Year 3	Year 4	Year 5
1	0	25	15	25	10
2	5	0	0	0	5
3	0	0	0	5	0
4	0	0	0	5	0
5	0	5	0	0	0
All disks	1	6	3	7	3

Table A.34. Percent average log and tree volume with decay from fire-killed lodgepole pines.

	Year 1	Year 2	Year 3	Year 4	Year 5
Log 1	0.02	0.12	0.04	0.18	0.15
Log 2	0.01	0	0	0.02	0.14
Log 3	0	0	0	0.05	0
Log 4	0	0.14	0	0.04	0
Tree	0.01	0.06	0	0.09	0.1

Table A.35. Percent disks with wood borer holes from fire-killed lodgepole pines.

Disk Position	Year 1	Year 2	Year 3	Year 4	Year 5
1	5	15	5	25	5
2	15	10	5	15	25
3	10	20	20	10	10
4	5	5	5	5	10
5	0	0	5	5	0
All disks	7	10	8	12	10

Ponderosa pine tables:

Table A.36. Percent disks with stain from fire-killed ponderosa pines.

Disk position	Year 1	Year 2	Year 3	Year 4	Year 5
1	95	90	100	80	-
2	80	95	100	90	-
3	60	95	95	90	-
4	70	95	100	80	-
5	75	95	100	70	-
All disks	76	94	99	82	85

Table A.37. Percent average log and tree volume with stain from fire-killed ponderosa pines.

	Year 1	Year 2	Year 3	Year 4	Year 5
Log 1	23.9	38.7	71.8	53.6	14.9
Log 2	20.4	54.7	75.7	64.8	20.2
Log 3	25.4	54.8	78.1	63.6	19.0
Log 4	37.2	62.3	87.7	60.9	15.5
Tree	24.3	48.7	75.4	59.3	17.2

Table A.38. Percent disks with cracks from fire-killed ponderosa pines.

Disk Position	Year 1	Year 2	Year 3	Year 4	Year 5
1	10	5	15	60	-
2	-	45	70	60	-
3	5	45	80	75	-
4	5	35	70	55	-
5	-	15	15	55	-
All disks	4	29	50	61	-

Table A.39. Percent average calculated log and tree volume affected by cracks in fire-killed ponderosa pines.

	Year 1	Year 2	Year 3	Year 4	Year 5
Log 1	13.7	12.2	11.2	35.5	13.9
Log 2	7.5	42.2	44.6	54.9	21.7
Log 3	34.9	53.8	53.4	46.3	22.5
Log 4	12.1	25.3	28.3	37.0	14.4
Tree	15.7	29.7	30.0	43.2	17.8

Table A.40. Percent disks with decay from fire-killed ponderosa pines.

Disk Position	Year 1	Year 2	Year 3	Year 4	Year 5
1	5	15	40	65	95
2	5	10	40	35	80
3	10	10	20	55	80
4	5	10	10	45	85
5	0	0	0	35	85
All disks	5	9	22	47	85

Table A.41. Percent average log and tree volume with decay from fire-killed ponderosa pines.

	Year 1	Year 2	Year 3	Year 4	Year 5
Log 1	0.2	1.0	3.5	20.4	77.5
Log 2	0.2	0.8	2.3	15.6	73.2
Log 3	0.3	1.9	1.0	24.2	75.7
Log 4	0.04	0.4	0.4	22.3	80.0
Tree	0.2	1.0	2.4	20.0	76.1

Table A.42. Percent disks with wood borer holes from fire-killed ponderosa pines.

Disk Position	Year 1	Year 2	Year 3	Year 4	Year 5
1	30	65	80	85	100
2	20	55	70	75	67
3	20	40	50	70	40
4	25	30	30	50	60
5	20	30	35	35	0
All disks	23	44	53	63	74

Engelmann Spruce tables:

Table A.43. Percent disks with stain from fire-killed Engelmann spruce.

Disk position	Year 1	Year 2	Year 3	Year 4	Year 5
1	100	100	100	100	95
2	95	100	95	100	95
3	90	95	95	100	100
4	70	80	90	90	95
5	50	75	35	30	47
All disks	57	90	83	84	86

Table A.44. Percent average log and tree volume with stain from fire-killed Engelmann spruces.

	Year 1	Year 2	Year 3	Year 4	Year 5
Log 1	18.1	24.3	23.3	25.9	30.7
Log 2	10.5	17.4	18.5	22.7	29.3
Log 3	6.8	15.7	15.6	24.8	33.0
Log 4	4.5	14.3	3.9	9.0	22.6
Tree	12.9	20.4	19.3	23.5	30.7

Table A.45. Percent disks with cracks from fire-killed Engelmann spruces.

Disk Position	Year 1	Year 2	Year 3	Year 4	Year 5
1	55	95	100	100	95
2	40	95	95	95	100
3	35	75	85	95	100
4	25	80	85	95	100
5	10	20	45	70	68
All disks	33	73	82	91	93

Table A.46. Percent average calculated log and tree volume affected by cracks in fire-killed Engelmann spruces.

	Year 1	Year 2	Year 3	Year 4	Year 5
Log 1	30.5	33.6	38.4	43.9	45.7
Log 2	41.3	42.3	48.4	59.1	64.4
Log 3	36.1	50.3	56.8	66.2	72.7
Log 4	28.1	31.3	44.9	60.8	60.5
Tree	34.5	38.5	44.8	53.4	57.1

Table A.47. Percent disks with decay from fire-killed Engelmann spruces.

Disk Position	Year 1	Year 2	Year 3	Year 4	Year 5
1	0	30	25	35	37
2	0	0	0	5	16
3	0	0	15	0	11
4	0	0	10	0	5
5	0	0	0	0	5
All disks	0	6	10	8	15

Table A.48. Percent average log and tree volume with decay from fire-killed Engelmann spruces.

	Year 1	Year 2	Year 3	Year 4	Year 5
Log 1	0	0.08	0.2	0.2	5.5
Log 2	0	0	0.1	0.1	3.2
Log 3	0	0	0.4	0	0.7
Log 4	0	0	0.1	0	0.2
Tree	0	0.04	0.1	0.1	3.6

Table A.49. Percent disks with wood borer holes from fire-killed Engelmann spruces.

Disk Position	Year 1	Year 2	Year 3	Year 4	Year 5
1	0	25	25	20	37
2	10	30	20	10	32
3	0	20	35	35	42
4	0	10	25	15	21
5	0	0	0	15	11
All disks	1	17	21	19	28

Abbreviations:

ABGR = Grand fir (Abies grandis)
ABLA = Subalpine fir (Abies lasiocarpa)
LAOC = Western larch (Larix occidentalis)
PICO = Lodgepole pine (Pinus contorta)
PIEN = Engelmann spruce (Picea engelmannii)
PIPO = Ponderosa pine (Pinus ponderosa)
PSME = Douglas-fir (Pseudotsuga menziesii)