Deterioration of Fire-Killed Timber in Southern Oregon and Northern California

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ABSTRACT. *Deterioration of fire-killed timber in the coastal mountains of southern Oregon and northern California was monitored over a 3 yr period (1988–1990). Defect was identified and measured on felled and bucked sample trees by using Scribner and cubic scaling rules. Douglas-fir* (Pseudotsuga menziesii), *grand fir* (Abies grandis), *white fir* (A. concolor), *ponderosa pine* (Pinus ponderosa), *and sugar pine* (Pinus lambertiana), *covering a wide range of geographic areas, site conditions, and tree size and age, were studied. One year after death, Douglas-fir, sugar pine, and ponderosa pine had lost about 1% and the true firs 5% of their cubic volume. The sapwood of the pines was heavily stained. The occurrence of sap rot and weather checks increased the second year. Percent loss in all species was correlated with small-end scaling diameter. A logistic regression model predicting the incidence of cull was developed for use on logs that have been dead for 3 yr. West. J. Appl. For. 11(4):125–131.*

Increased fire suppression efforts over the past 50 yr have led to increased opportunities for large fire events. Drought and insect epidemics have taken their toll on forest health, thereby increasing the possibility of catastrophic fire. Seven of the last 10 yr have seen over 2 million ac burned nationwide (unpublished data on file with National Interagency Fire Center, Boise, ID 1996). In 1987, over 900,000 ac were burned in California and Oregon, and land management agencies were quick to form recovery teams that developed plans to restore and salvage the burned areas. Projected deterioration rates for standing, fire-killed timber are important in determining how and when the timber can be salvaged. However, land managers were concerned that existing information from past deterioration studies was not available for younger (less than 250 yr old), smaller trees (less than 20 in. dbh) that had been dead 1 and 2 yr (Kimmey and Furniss 1943). The nature of the resource has changed over the years, and the average dbh of softwood trees harvested in the Northwest has decreased from 27.5 in. in 1976 to 17.9 in. in 1990 (Haynes et al. 1995). Also, they were concerned that data was not directly suited to the environmental conditions in the coastal regions of southern Oregon and northern California. Kimmey (1955) sampled only one area from the Coast Range, and that was in the second year after fire-kill. The stratified sample used in this study was designed to be representative of the current resource conditions.

Many factors such as species, position in tree, percent of sapwood, elevation, aspect, and fire severity and season influence rate of deterioration in standing, fire-killed timber (Kimmey and Furniss 1943, Kimmey 1955). Many combinations of these and other factors are present on any given site and will yield different rates of deterioration. It was not within the scope of this study to assess the impact of all these individual factors on the deterioration process, rather to provide volume loss estimates based on data collected over a broad range of conditions.

The primary objective of this study was to compare and contrast the volume deterioration of fire-killed timber in the coastal mountains of southern Oregon and northern California in trees dead from 1 (1988) to 3 yr (1990) for four commercial species: Douglas-fir (*Pseudotsuga menziesii*), grand fir (*Abies grandis*), and white fir (*A. concolor*) (hereafter referred to as "true fir"), ponderosa pine (*Pinus ponderosa*), and sugar pine (*Pinus lambertiana*).

Materials And Methods

Sample

Sample trees were selected from eight areas in the Siskiyou National Forest and on Bureau of Land Management (BLM) lands in southwestern Oregon and the Six Rivers and Klamath National Forests in northern California (Figure 1).

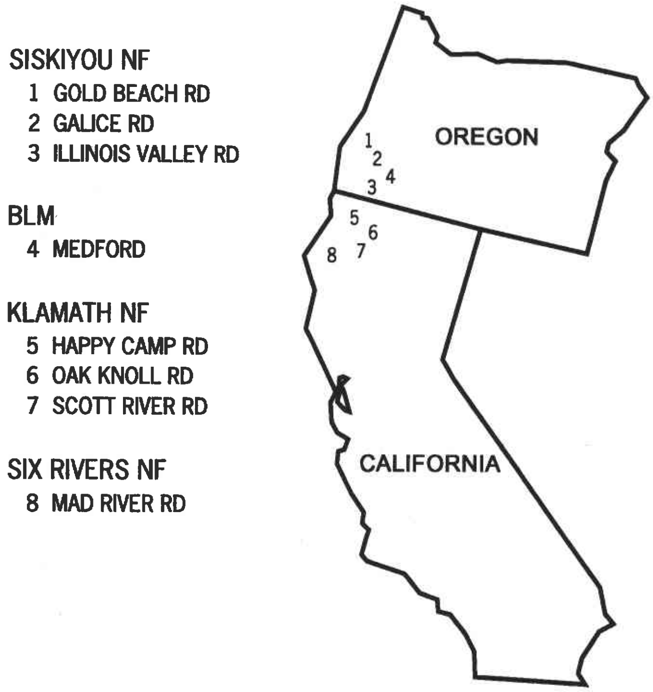

Figure 1. Sites sampled for fire-killed timber. NF is National Forest, RD is Ranger District, BLM is Bureau of Land Management.

Agency personnel agreed to set aside the areas for repetitive sampling throughout the 3 yr study. It was necessary to add additional sites from these same general areas in the second (10 sampling sites) and third (12 sampling sites) years to obtain enough trees for each species sampled. Sites varied by many factors including slope, elevation, aspect, precipitation, and fire intensity; and were not selected with the intent of comparing results among them. Site descriptions are given in Table 1.

Within the sample sites, trees were selected for study based on tree dbh, which ranged from 12 to over 40 in. and was stratified by 4 in. diameter classes. A target sample size of seven trees per diameter class per species per year was set. On each site, the range of species and dbh present were represented in the sample. A sample cell was not filled with trees from one site. Summaries of the sample are shown in Table 2.

Scaling Procedure

Trees were felled and bucked into 16 ft log lengths to a merchantable diameter of 6 in. The length of the top log varied. Log and defect volume were measured by USDA Forest Service (Pacific Northwest and Pacific Southwest Regions) and BLM (Oregon State office) scalers using standard log scaling procedures. The logs were scaled using Scribner (USDA Forest Service 1985) and cubic (USDA Forest Service 1978) rules. Scalers were instructed to measure and deduct for sap rot, weather checks, and char. Defects not related to fire damage or deterioration (e.g., heart rot or heart checks) were not recorded. Disks were cut from every bucking point and evaluated for the presence of sap rot, weather checks, and blue stain. Deterioration was calculated as a percentage of volume loss in each log. Logs were considered cull (not usable) if the merchantable volume was less than 33% for cubic scale. Data from all logs were used in the analysis.

Statistical Analysis

For each species, a nested analysis of variance (Snedecor and Cochran 1980) was used to determine the source of variation in the data set and to quantify the variability. These results would verify that the data was being analyzed on the appropriate scale using the correct sampling unit (logs).

Linear regression analysis (Snedecor and Cochran 1980) was used to determine the significance of log small-end diameter or some transformation of it (independent variable) on cubic volume loss (dependent variable). When similarities among species occurred in the results, analysis of covariance (a comparison of the regression lines), was performed to determine if the volume loss was significantly different among or between species (Neter and

Table 1. Summary of site characteristics.

Landowner	Ranger district	Site	Elevation (ft)	Aspect	Precip. (in.)	Overstory	Burn intensity
USFS							
Siskiyou NF	Galice	Bald Mt.	3400	S	60–80	Douglas-fir	Moderate
	Illinois Valley	Longwood	2800	SE	40	Mixed conifer	High
	Gold Beach	Fishhook Peak	4200	SW	60	White fir/Douglas-fir	Light-moderate
Klamath NF	Oak Knoll	Copper Mt.	3200	S	30	Ponderosa pine/Douglas-fir	High
	Oak Knoll	Grider Ridge	4000	N-NE	40	Ponderosa pine/Douglas-fir	Light
	Happy Camp	Titus Ridge	4000	W	45–65	Douglas-fir	High
	Happy Camp	Below Road	3000	S	35–60	Douglas-fir	Light-moderate
	Happy Camp	Tie Road	3200	S	35–60	Douglas-fir	Light-moderate
	Happy Camp	Yard Sale	3700	S	35–60	Douglas-fir/ponderosa pine	Light-moderate
	Happy Camp	Kanaka Sale	3000	NW	35–60	Mixed conifer	Light-moderate
	Scott River	Leave Trees	5600	S	40	Mixed conifer	High
	Scott River	Rattler	5400	SE	40	Mixed conifer	High
	Scott River	Road End	6200	S	40	True fir	High
Six Rivers NF	Mad River	Blake Mt.	5500	NW	60	True fir	Moderate
	Mad River	Travis Mt.	4100	NE	60	White fir/Douglas-fir	High
BLM	Medford	Star Gulch	2400	W	30–35	Douglas-fir/ponderosa pine	High
	Medford	Jamison Cove	2500	S-SE	30–35	Mixed conifer	High

Table 2. Sample summary for all species for all years.

Years dead	Species	Number of sites	Number of trees	Range in age (yr)	Range in dbh (in.)	Number of logs	Range in log diameter (in.)
1	Douglas-fir	3	54	50–297	10–48	285	6–34
	True fir	4	49	50–325	11–44	244	6–38
	Ponderosa pine	3	33	70–442	13–41	170	6–34
	Sugar pine	3	25	98–227	19–40	144	6–34
2	Douglas-fir	6	47	70–290	12–50	246	6–38
	True fir	3	46	55–231	12–54	251	6–43
	Ponderosa pine	4	27	82–325	13–36	119	6–29
	Sugar pine	4	34	77–306	12–44	182	6–37
3	Douglas-fir	6	54	75–294	12–59	337	6–46
	True fir	5	49	64–232	12–54	292	6–41
	Ponderosa pine	7	38	84–300	12–41	215	6–33
	Sugar pine	7	37	54–272	12–58	211	6–48

Wasserman 1974). A significance level of 0.05 was used in all statistical tests. Regression models predicting the amount of volume loss were developed based on the outcome of these statistical tests.

Because a large number of logs from 3 yr dead trees had a high defect percentage, a two-step analysis was used to determine deterioration rate in the third year after death. The first step was to perform a logistic regression (Hosmer and Lemeshow 1989) to determine the probability of a log being culled (less than 33% merchantable wood cubic volume). The second step involved using regression analysis on the remaining noncull log data to determine if there was a relationship between log small-end diameter (independent variable) and amount of defect (dependent variable).

Results

Results (Table 3) from the nested ANOVA show that most of the variability occurred among logs within trees with little variability accounted for by site. An exception was in the true fir sample, where site accounted for about one-third of the variability in the second and third years. The amount of variability between logs decreased in year 3 for Douglas-fir and ponderosa pine but remained the major source of variability. For sugar pine, the variation attributed to logs remained about the same for the 2- and 3-yr-dead sample. Because of these findings, the sampling unit used in data analysis was logs.

Table 3. Source of variation in data as determined by a nested analysis of variance.

Species	Source	Year 1	2	3
			(%)	
Douglas-fir	Site	0	4	12
	Tree (site)	39	3	12
	Log (tree)	61	93	76
Ponderosa pine	Site	8	3	29
	Tree (site)	11	4	6
	Log (tree)	81	93	65
Sugar pine	Site	6	5	1
	Tree (site)	3	20	22
	Log (tree)	91	75	77
True fir	Site	6	33	30
	Tree (site)	0	19	14
	Log (tree)	94	48	56

Volume loss results are presented in terms of cubic foot volume. Scribner volume loss followed similar trends with the percentage of losses being slightly higher than cubic values. (Additional information is available from the authors.)

One-Year Dead

In the first year after the trees were killed by fire, very little defect was observed and volume loss, as defined by scaling rules, was minimal. There was some bark sloughing off the top logs of trees, especially in the true firs, while on the lower logs the bark remained tight for all species. Fine branches and needles, depending on the severity of the burn, were still clearly evident on trees examined. Insect activity, primarily bark beetles, was noticed throughout the merchantable bole at all sample sites. Weather checks in the upper logs were the primary cause for scale deductions. No char deductions were made.

Percentage of cubic volume lost for each species was minimal (Table 4). There was little visible sap rot present in the trees sampled. Only 1% of all logs (8 true fir, 2 ponderosa pine, 1 sugar pine) required a scale deduction for sap rot.

Five percent of all logs required scale deductions for weather checks. A typical deduction for weather check was a diameter reduction of 1 to 2 in. for the top log of the tree. In smaller diameter logs, this deduction can often be a significant portion of the log volume, thereby causing the log to be classified a cull. For 20 of the 27 true fir logs containing a scale deduction, the cause was weather checks. These 20 logs

Table 4. Mean cubic volume loss, primarily from weather checking, for all logs the first year after being killed by fire.

Species	Mean cubic volume loss %	Range	SE [1]
Douglas-fir	1	0–100	0.36
Ponderosa pine	1	0–16	0.15
Sugar pine	1	0–13	0.13
True fir	5	0–100	1.25

[1] Standard error of mean percent cubic volume loss.

all came from the upper portion of the bole, and 9 were top logs culled because of this defect. This is reflected in Table 4, where the range of mean cubic volume loss extends to 100% for true fir and Douglas-fir. The higher incidence of weather-checking in upper logs of true fir account for its larger volume loss.

Linear regression analysis for Douglas-fir, ponderosa pine, and sugar pine showed very little relation between cubic volume loss and log small-end diameter. The model for true fir was significant ($P = 0.0001$) with a weak correlation ($r^2 = 0.19$) and can be used to calculate cubic loss in 1-yr-dead logs. The relation is described by the following equation:

$$\text{Cubic volume loss (\%)} = -10.41 + (199.54) * (1/\text{log small diameter})$$

Blue stain was present in significant amounts in ponderosa and sugar pine. The sapwood of the sugar pine sample was completely stained. Stain was present to a lesser extent in the ponderosa pine and occurred in a streaky pattern.

Two-Year Dead

By the second year, an increase in outward signs of deterioration was evident. Insect activity could be detected from small piles of bark dust on the tree boles, conks (*Cryptoporous volvatus* [Pk.] Shear) were visible on the stems (Figure 2), and loose or sloughing bark was observed in the upper boles of trees more often than in the first year after fire. Blue stain had increased slightly in ponderosa pine, but still occurred in a streaky pattern (Figure 3). The incidence of breakage during felling increased on some of the sites with rougher terrain. Again, no deductions were made for char.

The occurrence of sap rot increased dramatically (44% of the logs) by the second year. Although the number of logs containing sap rot was high, the volume affected by this defect was not great. Small areas, or pockets of sap rot (Figure 2), were commonly observed for this type of defect.

Fourteen percent of all logs sampled in 1989 had a deduction for weather checks. The amount of deterioration observed from weather checking also increased from the previous year. Mean cubic volume loss in logs with weather checking was higher than that for sap rot. Most of the weather checking occurred in the small-diameter, upper logs. Mean diameter of logs with this defect was 9.6 in. as compared to logs with sap rot which had a mean diameter of 17.2 in. In Douglas-fir and true fir, over one-half of the logs with weather checks were cull, whereas less than 25% of the pine logs with weather check were cull.

When defect is averaged over all logs within a species group, percent volume loss is less than 10% for every species. The amount of defect, and the proportion attributable to each defect type, is shown by year for each species in Figure 4.

The analysis of covariance comparing total cubic volume loss by log small-end diameter indicated that there was no significant difference between Douglas-fir and true fir or between ponderosa and sugar pine. Models were developed for predicting the cubic volume loss in the combined firs and the combined pines (Figure 5) to be used in calculating percent of cubic volume loss in logs from 2-yr-dead fire-killed trees.

Three-Year Dead

At the end of the third year, the percent of logs (78%) containing sap rot had close to doubled from the previous year. Many of the conks evident the previous year had dried up or fallen off. The proportion of logs with deductions for sap rot in 3-yr-dead material went from about

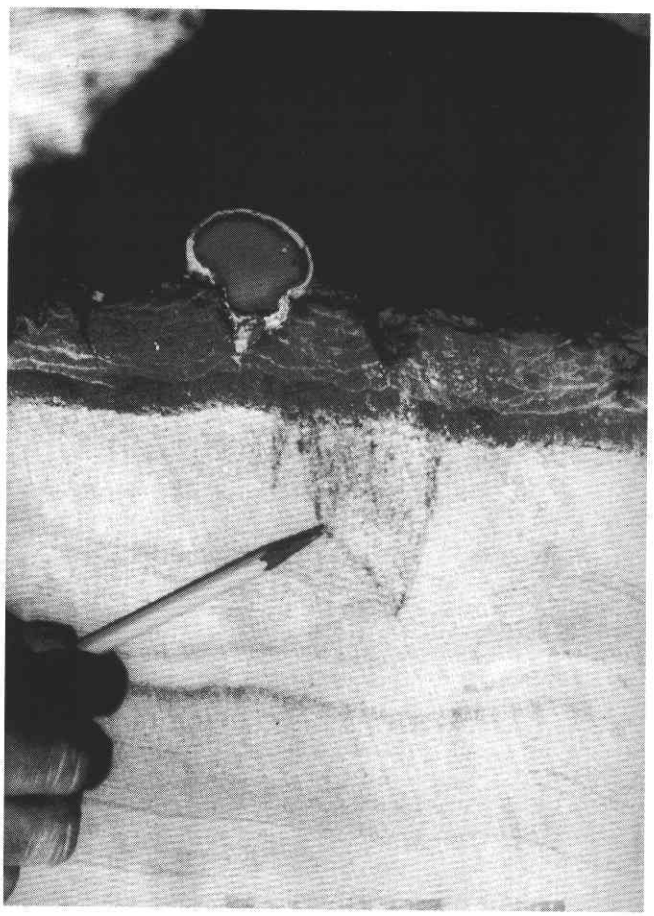

Figure 2. Two-year-dead Douglas-fir sample showing a *C. volvatus* conk and an adjacent pocket of sap rot.

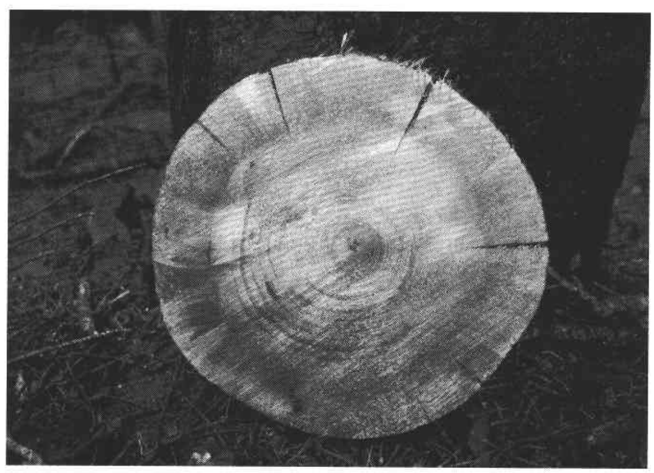

Figure 3. Two-year-dead ponderosa pine showing blue-stained sapwood and deep weather checks.

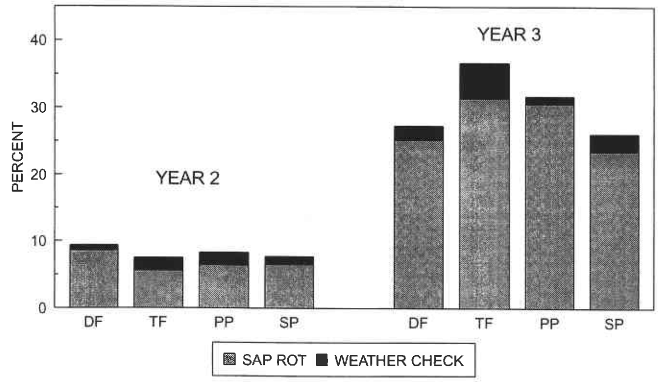

Figure 4. Total cubic volume loss for each species by year broken down into proportions that were from sap rot and weather check. DF is Douglas-fir, TF is true fir, PP is ponderosa pine, and SP is sugar pine.

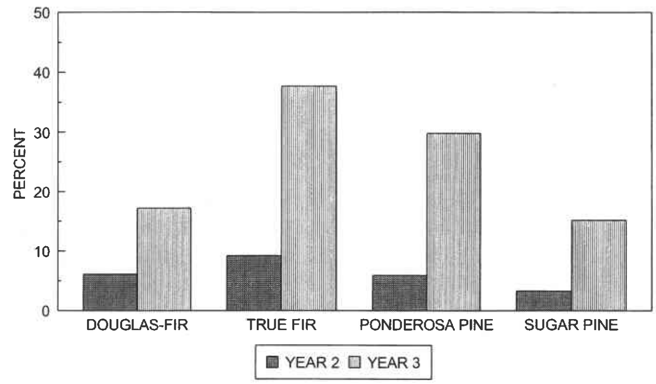

Figure 6. Percent of logs that were cull in each species for 2 and 3 yr after being killed by fire.

one-third to three-quarters in ponderosa pine and true fir and increased 30% in Douglas-fir and sugar pine. The cubic volume loss in logs containing sap rot more than doubled for all species except Douglas-fir. No heartwood damage was observed.

Incidence of weather checks increased to 17% of all the logs sampled in 3-yr-dead material. As in the second year, the mean diameter of logs with weather checks was small, 9.5 in., and much less than logs with sap rot (18.1 in. mean small diameter). Volume loss in logs with weather checks was very high in Douglas-fir, ponderosa pine, and true fir. In these species, the weather check damage was severe enough to cull many of the logs. Overall, sap rot represented a much larger proportion of total defect within a species (Figure 4) than weather checking.

The incidence of cull logs increased with 26% of all logs being culled and the amount of cull logs varied by species (Figure 6). For each species, the logistic regression model, which predicts the probability of a log being cull, was highly significant (P = 0.0001) as measured by the likelihood ratio test statistic. Calculated probabilities of a 3-yr-dead log being cull, as determined by the logistic regression, are shown in Table 5 by species. The probability of being cull is high for small logs ranging from 93% for a 6 in. true fir log to 55% for a 6 in. sugar pine log.

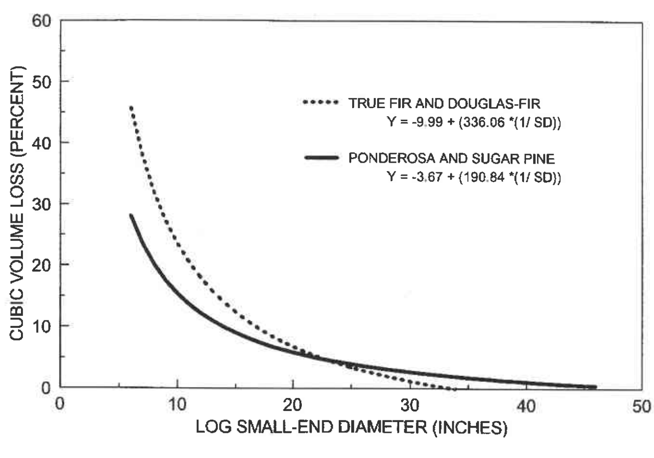

Figure 5. Regression curves for combined firs (Douglas and true) and pines (ponderosa and sugar) showing relation between log small-end diameter and percentage of cubic volume loss.

Probability reaches zero by 19 in. for Douglas-fir, 21 in. for sugar pine, 28 in. for true fir, and 31 in. for ponderosa pine.

Regression analyses for ponderosa pine, sugar pine, and true fir noncull logs indicated no statistically significant relation between log small-end diameter and percentage of cubic volume loss. The mean cubic volume loss for all noncull logs was 23% for ponderosa pine, 24% for sugar pine, and 28% for true fir.

For Douglas-fir, the regression analysis to predict percent cubic volume loss for noncull logs by log small diameter was significant ($P = 0.0001$) with a weak correlation ($r^2 = 0.10$). The regression equation to be used for noncull Douglas-fir logs is:

Table 5. Probability that a fire-killed, 3-yr-dead log is cull.

Log small diameter (in.)	Douglas-fir	Ponderosa pine	Sugar pine	True fir
		(%)		
6	68	72	55	93
7	57	66	46	90
8	45	60	37	86
9	34	54	29	81
10	24	48	22	75
11	16	41	16	68
12	11	35	12	60
13	7	30	8	51
14	4	25	6	42
15	3	20	4	34
16	2	17	3	26
17	1	13	2	20
18	1	11	1	15
19	0	8	1	11
20	0	7	1	8
21	0	5	0	6
22	0	4	0	4
23	0	3	0	3
24	0	3	0	2
25	0	2	0	1
26	0	2	0	1
27	0	1	0	1
28	0	1	0	0
29	0	1	0	0
30	0	1	0	0
31	0	0	0	0
32	0	0	0	0
33	0	0	0	0
34	0	0	0	0

$$\text{Cubic volume loss (\%)} = 38.5713 - (.5531) * (\text{log small-end diameter})$$

Discussion

The two primary defects requiring scale deductions and which affect product yield in fire-killed trees are weather checks and sap rot. In both the Kimmey and Furniss (1943) and Kimmey (1955) studies, volume loss from weather checking was minimal and not included in volume loss estimates. Weather checking is influenced by such factors as bark thickness and intensity of fire. Tree species with thin bark are less resistant to fire (Starker 1934) and subsequently are more prone to moisture loss which creates unfavorable conditions for sap rot development (Basham 1957) but increases susceptibility to developing weather checks. Weather checking is more commonly found in top logs that receive more exposure to the elements and where the bark is thinner (Kimmey 1955). Hot, dry, or windy sites are also more susceptible to checking. When the fire intensity is high, much of a tree's moisture may be removed, resulting in an increased amount of weather checking. True fir, a thin-barked species, had a higher occurrence of weather checking the first year after the fires. Much of this deterioration was found on one of the high elevation sites where the burn intensity was high. Smaller diameter logs from true fir and Douglas-fir lost more volume from weather checking than the pines. Two and 3 yr after being burned, mean diameter of weather-checked logs was smaller than that of logs with sap rot for all species.

Sap rot decreases the usable volume of a log and decreases the strength properties of wood (Kennedy 1958), making it unsuitable for products manufactured for structural purposes. Fungi responsible for sap rot enter the tree through cracks in the bark (insect bore holes, weather checks, or broken tops) or can be carried in on the body of an insect. Brown rot fungi are the primary sapwood decay agents initially found in fire-killed timber (Wallis et al. 1974). The pouch fungus conks which were observed in this study are a brown rot fungi. Incipient decay, which cannot be detected visually (Wilcox 1978), may have been present the first year after fire-kill, but very few scaling deductions were made for sap rot this first year. This differs from the previous studies (Kimmey and Furniss 1943, Kimmey 1955) where greater cubic volume losses were found in Douglas-fir and white fir. By the second year, pockets of rot large enough to warrant a scaling deduction had developed in the logs. Sapwood is very susceptible to decay (Panshin and de Zeeuw 1964), and the high percentage of sapwood in some species increases its cubic volume loss over that of other species. The second year after the fire, pine logs greater than 23 in. lost more volume than fir logs (Figure 5), most likely due to their higher percentage of sapwood and the corresponding increase in sap rot.

Blue stain, while not a scaling deduction, is an important form of deterioration affecting the sapwood of almost all species. Blue stain probably causes the largest economic loss associated with the use of 1-yr-dead pine sawtimber. Most affected by stain are lumber products (Select, Shop, and Moulding lumber) that are graded for appearance (Fahey 1980) and typically manufactured from the outer portion (sapwood) of a log. Species used for these products or ones that have a high proportion of sapwood, such as ponderosa and sugar pine, will experience greater value losses. The sapwood in ponderosa pine makes up 50 to 75% of a tree's gross cubic volume and in sugar pine constitutes 25 to 70% of a tree's gross cubic volume (Kimmey 1955). In this study, the sapwood of sugar pine was almost entirely blue stained and that of ponderosa pine stained in a streaked pattern 1 yr after fire-kill. This was more than what Kimmey (1955) observed in sugar pine. Both this, and the Kimmey (1955) study, found no blue stain in true fir or Douglas-fir.

Most stands contained a majority of trees that would be suitable for lumber or veneer production with very little loss in yields. When a large number of logs are to be evaluated, applying the mean cubic volume loss for Douglas-fir, ponderosa pine, and sugar pine (Table 3) the first year after a fire should provide a reasonable estimate of volume recovery. The regression model should be used for true fir, as the smaller logs are more susceptible to weather checking.

The second year after fire-kill, similarities in the deterioration rates of the pines and firs were noted resulting in a single regression model for each species group to predict cubic volume loss (Figure 5).

Because of the high proportion of cull logs in logs from fire-killed trees 3 yr after the fire, especially in ponderosa pine and true fir, a two-step procedure for estimating volume loss is recommended. The first step is using the logistic regression model for each species to predict the percent of logs at each diameter that will be cull and remove them from the database. The second step is to apply a single volume loss coefficient (ponderosa pine, sugar pine, and true fir) or the regression model (Douglas-fir) to the remainder of the sample. Here is an example of how this would work: A cruise of 3-yr-dead fire-killed timber shows a gross volume of 690 ft^3 in 6 in. ponderosa pine logs. The probability of a 6 in. log being cull is 72%. Therefore, 72% of the volume, or 496 ft^3, will be cull leaving 193 ft^3. In that 193 ft^3, there will be a 23% volume reduction of 44 ft^3. The total merchantable volume for 6 in. ponderosa pine logs will be 148 ft^3.

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