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Lumber Recovery and Deterioration of Beetle-Killed Douglas-fir and Grand-fir in the Blue Mountains of Eastern Oregon

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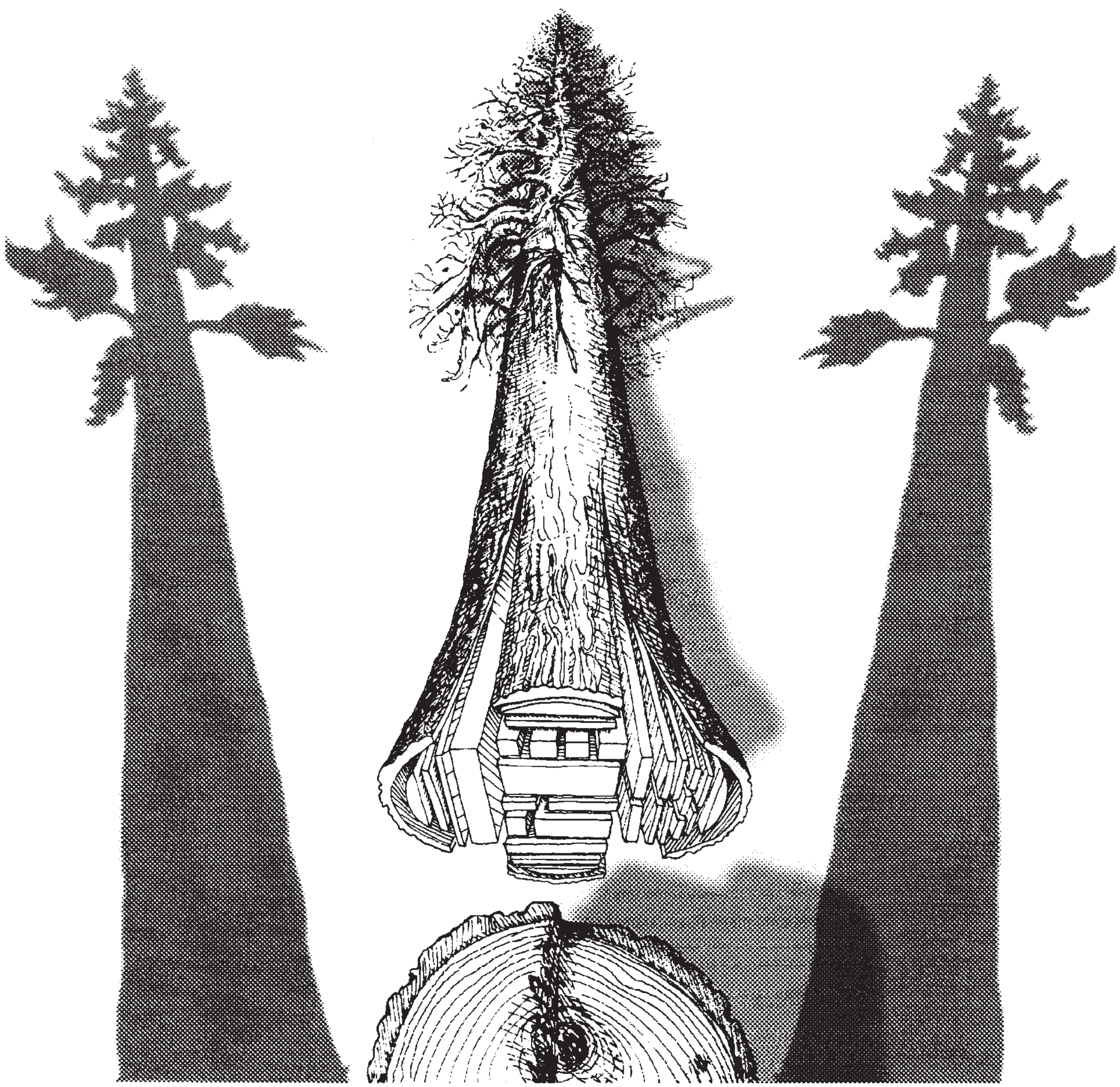

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Abstract

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The purpose of this study was to determine the effect of time since death over a 4-year period on the amount of usable product volume and value, and to determine the species of fungi associated with wood deterioration in the stems of Douglas-fir and grand fir trees killed by bark beetles in northeastern Oregon. Sap rot, caused principally by *Cryptoporus volvatus*, increased significantly with years dead for both Douglas-fir and grand fir, but there were no significant differences in sap rot among d.b.h. (diameter at breast height) classes. Few insects were associated with defective wood, probably because of the relatively dry condition of the wood. Log breakage during logging in the live samples was less than 0.5 percent of the gross volume, and the amount of wood too defective to remove from the woods was about 2.5 percent in the dead Douglas-fir and 3.8 percent in the dead grand fir. Two-year-dead Douglas-fir recovered about 8 percent less lumber volume than live and 1-year dead Douglas-fir and all classes of dead grand fir. Three- and four-year dead Douglas-fir combined lost another 7 percent in lumber volume. Average lumber value (dollars per thousand lumber tally) and average log value (dollars per hundred cubic feet) analysis showed no difference among the live and 1-year-dead Douglas-fir samples. Average log value decreased about $60 from the live class to the grand fir dead class and another $60 for the Douglas-fir dead. Contrary to popular belief, the grand fir did not deteriorate as fast as the Douglas-fir or lose as much value as expected.

Keywords: Douglas-fir, *Pseudotsuga menziesii*, grand fir, *Abies grandis*, lumber recovery, utilization, dead timber, western spruce budworm, *Choristoneura occidentalis, Douglas-fir beetle, Dendroctonus pseudotsugae* Hopkins, fir engraver, *Cryptoporus volvatus, Trichaptum (Polyporus) abieinum, Fomitopsis pinicola.*

Contents

Introduction

Douglas-fir *(Pseudotsuga menziesii* (Mirb.) Franco) is found from northern California to British Columbia and as far east as the Rocky Mountains (Burns and Honkala 1990). In the inland Northwest, Douglas-fir and western larch (*Larix occidentalis* Nutt.) are processed and marketed together as a species group and make up 24 percent of all softwood lumber production. The total production of Douglas-fir and larch in 1993 was 2 billion board feet. It was used for dimension lumber, timbers, and studs, accounting for over 75 percent of log and lumber exports from eastern Oregon and Washington (Warren 1994).

Grand fir *(Abies grandis* (Dougl. ex D. Don) Lindl.) is found in moister sites such as stream bottoms and valleys or mountain slopes in the northwestern United States and southern British Columbia. In the Inland Empire, it is found in southern British Columbia, eastern Washington and Oregon, and the regions of western Montana and northern Idaho west of the Continental Divide. It grows best on rich mineral soils in valley bottoms but also will grow in pumice soils such as those found in central and eastern Oregon, if rainfall is adequate (Burns and Honkala 1990). The primary uses of grand fir lumber are dimension lumber, timbers, and studs (Western Wood Products Association 1995).

Since the late 1970s, Douglas-fir in the Blue Mountains of eastern Oregon has been subjected to outbreaks of a defoliator, western spruce budworm *(Choristoneura occidentalis* Freeman), and a bark beetle, the Douglas-fir beetle *(Dendroctonus pseudotsugae* Hopkins). Grand fir also has been subjected to severe defoliation by western spruce budworm and attacks by another bark beetle, the fir engraver *(Scolytus ventralis* LeConte). According to rainfall records collected by the Oregon Climate Service, below normal rainfall was received in the La Grande, Oregon, area from 1985 through 1992. According to data from the Oregon Climate Service, for those years, rainfall amounts dropped as low as 71 percent and was no greater than 86 percent of the previous yearly normal. During the drought period, most of the shortfall occurred from September through April and produced much less snowpack than usual.[1] This drought reduced the natural defense mechanisms of the trees to an extent such that the trees could not resist the attacks of bark beetle infestations (Wright and Lejeune 1967). The result has been significant mortality of Douglas-fir and grand fir trees. Our observations indicated that the most severe Douglas-fir mortality occurred on dry sites where ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.) has historically been the more common species.

About 100 million board feet of Douglas-fir and over 280 million board feet of grand fir in the Blue Mountains of Oregon and Washington has been killed as a result of drought and insect epidemics from 1992 through 1994 (USDA 1994). The rate of deterioration of beetle-killed trees is of primary concern to forest managers and is important in the scheduling of prompt salvage operations in affected forests. Resource managers need guidelines to use in planning for management of this important forest resource. One alternative is to remove the dead trees for production of wood products. The purpose of this study was to determine the effect of time since death on the amount of usable product volume and value. We also determined the species of decay-causing fungi associated with wood deterioration in the stems of trees killed by bark beetles over a 4-year period in northeastern Oregon.

[1] Personal communication. 1995. Chris Scalley, Oregon Climate Service, Oregon State University, Corvallis, OR 97331-2209.

Literature Review

It is important to understand the types of deterioration agents and their progression in trees that are stressed and dying or recently dead. This information is essential to developing reliable estimates of the rates of decay and the impact of the deterioration on volume and value loss. The following review provides background on the insects and fungi and on existing work covering lumber volume and value loss in dead timber.

The Douglas-fir beetle and fir engraver are bark beetles and they mine only in the cambium. Except for loosening the bark and serving as a carrier of fungal spores, they cause no damage to wood. Wood boring beetles are the only insects causing direct significant wood damage (Wright and Harvey 1967).

Both species of bark beetle have a history of attacking trees that are physiologically stressed. The Douglas-fir beetle has one generation annually. Adults and large larvae overwinter, with adults predominating. Depending on area and weather, the over-wintering adults emerge and attack from April to June. Some of the adults reemerge, attack additional trees, and establish a second brood. Adults from overwintering larvae emerge and attack in July and August. "Reddish or yellowish boring dust caught in bark crevices or around the base of trees is the usual evidence of attack by the Douglas-fir beetle. No pitch tube is formed but resin may exude from upper attacks. The foliage of attacked trees turns yellow, then sorrel, and finally reddish brown in late summer, in fall, or in early spring, depending upon the region, time of attack, and weather" (Furniss and Carolin 1977: 357).

The Douglas-fir beetle is associated with the stain fungus *Ophiostoma pseudotsugae* (Rumb.) von Arx, but relatively little is known about the relation between beetle and fungus or about the succession of fungi or insects following infection by *O. pseudotsugae*. Extensive studies have been done on the fir engraver and its associated stain fungus, *Trichosporium symbioticum* Wright, (Berryman 1969, Filip and others 1989, Raffa and Berryman 1982, Wright 1935), but for it too, there is a lack of information on postinfection successional fungi and insects.

Wright and Wright (1954) briefly explored fungal succession in beetle-killed Douglas-fir in coastal Oregon and Washington. They found that the pouch fungus *(Cryptoporus volvatus* (Pk.) Shear.) frequently was found in trees killed 1 year previously by beetles. Sporophores of this fungus indicated a shallow rot of the sapwood. On trees dead for 2 or more years, rudimentary sporophores of the red-belt fungus *(Fomitopsis pinicola* (Swartz ex Fr.) Karst.) were common. Presence of these sporophores indicated an advanced stage of decay where the sapwood was destroyed and the heartwood sometimes invaded. Both species of fungi have been isolated from the Douglas-fir beetle (Castello and others 1976), which may be a vector (carrier) for these decay fungi as suggested by Wright and Wright (1954).

Thomas and Craig (1958) also briefly investigated the succession of fungi in dead Douglas-fir in interior British Columbia. They found that over a 5-year period, most of the sap rot was associated with two species of fungi: *Trichaptum (Polyporus) abietinum* (Dicks. ex Fr.) Ryv., and *F. pinicola*. *Cryptoporus volvatus* rarely caused extensive decay, although the abundance of its fruiting suggested greater decay than actually occurred. Eleven other species of fungi were identified. Heart rot fungi, those present before tree mortality, were not an important factor in the deterioration of dead Douglas-fir.

Although similar studies concerning deterioration of dead grand fir have not been reported, it is common knowledge among foresters that dead grand fir deteriorates much faster than Douglas-fir, and conks of *C. volvatus* are often found on trunks of dead grand fir and Douglas-fir trees. The rates of tree deterioration and causal fungi need to be studied. Most of the investigations concerning the succession of fungi associated with dead trees have been done in the relatively wet climate of coastal Oregon. The much drier climatic conditions in eastern Oregon may be sufficiently different to affect species of fungi and resultant deterioration rates of dead Douglas-fir and grand fir.

Use of the dead material has the advantage of reducing fuel loads and providing wood products for the consumer. Before salvage of the material can be considered, basic information about the products that can be recovered from the dead material is needed. It has been shown (Fahey and others 1986, Snellgrove and Ernst 1983) that product volume and value depend on the type of product produced and the time-since-death of the trees. Volume recovery is impacted by both sap rot and weather checking. Sap rot affects the ability to produce lumber from the outer section of the log, and weather checks produce splits in the logs and boards that result in narrower lumber. Value recovery is more significantly impacted in species such as ponderosa pine or western white pine (*Pinus monticola* (Dougl. ex D. Don)), which produce high-value appearance-grade lumber and in which blue stain in the sapwood occurs within the first year after death. Information available on Douglas-fir shows that it has thin sapwood and that trees 3 to 4 years dead in western Oregon and northern California lose 50 percent of their cubic volume (Kimmey and Furniss 1943). Another study on Douglas-fir (Wallis and others 1974) found a loss in lumber value of 7 percent, 11 percent, and 14 percent for trees dead 2, 3, and 4 years, respectively. True fir species have very thin bark and very thick sapwood and lose 50 percent of their cubic volume by the end of the second year after death (Kimmey 1955). A study of lumber recovery from live and 2-year-dead grand fir and white fir (*Abies concolor* (Gord. and Glend.) Lindl.) in eastern Oregon found a 6-percent increase in logging and handling losses, an 8-percent loss in lumber volume, and a 24-percent loss in lumber value for the dead sample (Snellgrove and Fahey 1977).

Objectives

There were three objectives in this study: to develop product recovery information for live and beetle-killed Douglas-fir and grand fir trees from eastern Oregon, to determine the rate of volume and value loss that occurs in beetle-killed trees over time, and to identify biotic agents responsible for deterioration of Douglas-fir and grand fir.

Field Procedures

Timber Sample

The sample for this study was selected from two sources, the Starkey Experimental Forest, in the Wallowa-Whitman National Forest of northeastern Oregon, and, the Vail District, Bureau of Land Management (BLM), near Union, Oregon. Twelve sites were used for sample selection in the Starkey Experimental Forest, and one site was selected from BLM land. The BLM site yielded 3 Douglas-fir and 68 grand fir trees. The Starkey Experimental Forest yielded 147 Douglas-fir and 39 grand fir trees.

The sampling procedure for both live and beetle-killed trees was designed to represent the variation of size and quality of the resource, and not to be a representative sample of the average log mix that a mill might process in a normal production run. Sampling criteria for Douglas-fir was diameter at breast height (d.b.h.) and grade of the butt 16-foot log from the inland Douglas-fir saw-log grading system (Lane 1964). The grand fir sample was stratified by d.b.h. only. Diameter at breast height for both species ranged from 10 to 30 inches and was selected by 5-inch diameter classes

Table 1—Number of sample trees by deterioration and diameter classes, log grade, and species

Deterioration and diameter class	Douglas-fir inland log grade 1	2	3	Grand fir
Inches		*Number of trees*		
Live:				
10.0 to 15.9	5	5	4	8
16.0 to 20.9	4	6	4	11
21.0 to 25.9	3	3	6	9
26.0 to 30.9	4	4	5	6
Total	16	18	19	34
1-year dead:				
10.0 to 15.9	1	1	0	6
16.0 to 20.9	2	0	1	5
21.0 to 25.9	0	1	0	7
26.0 to 30.9	1	0	1	2
Total	4	2	2	20
2-year dead:				
10.0 to 15.9	3	3	1	0
16.0 to 20.9	3	3	2	0
21.0 to 25.9	2	3	3	0
26.0 to 30.9	1	1	1	0
Total	9	10	7	0
3-year dead:				
10.0 to 15.9	3	3	1	11
16.0 to 20.9	3	3	3	9
21.0 to 25.9	3	3	3	9
26.0 to 30.9	3	3	4	2
Total	12	12	11	31
4-year dead:				
10.0 to 15.9	3	3	2	9
16.0 to 20.9	3	3	3	9
21.0 to 25.9	4	3	3	4
26.0 to 30.9	3	3	3	0
Total	13	12	11	22

(table 1). To select a sample that included trees dead up to 4 years, trees were selected in 1991, 1992, and 1993. Because of the difficulty of determining with certainty the year of death of trees that have been dead for several years, freshly killed trees were selected each year. Only presently dying, 1- or 2-year-dead trees were selected in any given year. Personnel from the La Grande Ranger District of the Wallowa-Whitman National Forest were present at the beginning of sample selection to train the sample selection team in identifying the year of death.

A list of traits follows that was used to determine when a Douglas-fir and grand fir tree died:

Douglas-fir

Part of tree:	What to look for:
	Trees killed during the current year
Bark surface	Fresh, rich brown frass in bark crevices or hanging from spider webbing
Beneath bark	Cambium discolored, adult galleries present and containing eggs or larvae
Needles	Green or slightly faded
Conks	None present
	Trees killed the previous year
Bark surface	Frass somewhat faded looking compared to fresh; washed from spider webs into bark crevices
Beneath bark	Cambium contains old galleries and frass; gallery-mining evidence on surface of wood
Needles	Brick-red color; nearly all still present on tree
Conks	Pouch fungus conks present on the bark are soft and moist
	Trees killed 2 years ago
Bark surface	Most frass has been washed from the bark crevices and deposited at base of tree
Beneath bark	Although all bark is present, it is quite loose from the bole of the tree
Needles	Only 25 percent or less of the needles remain; those present are still brick red
Conks	Pouch fungus conks are present, and open on the bottom; some conks have fallen off; those still present are hard and dry

Grand fir

Part of tree:	What to look for:
	Trees killed during the current year
Bark surface	0.06-inch adult exit holes
Beneath bark	Fir engraver galleries present around the circumference of the tree (tree girdled, bark loose)
Needles	Slightly faded green
Conks	None present
	Trees dead the previous year
Bark surface	Adult insect exit holes
Beneath bark	Galleries present; fungus mycelium present; incipient decay present in wood
Needles	Faded green to light brown color
Conks	Pouch fungus conks present are soft and moist

Decay and Fungal Samples

A subsample of trees were sampled in June 1993 at the Starkey Experimental forest (mostly Douglas-fir) and from BLM land southeast of Union, Oregon (mostly grand fir). For the decay and fungal sample portion of this study, 204 trees were sampled (117 Douglas-fir and 87 grand fir), with at least 25 trees from each of four mortality classes (dead 0, 2, 3, or 4 years) for Douglas-fir and at least 20 trees for three mortality classes (dead 0, 3, or 4 years) for grand fir. Within each mortality class, the trees were selected based on d.b.h., with at least three trees for each diameter class.

Felling and Bucking

Trees were felled and bucked into the cooperating mill's preferred log length of 40 feet. Other log lengths were determined by merchantable tree length or the occurrence of breaks down to a minimum top diameter of 5.6 inches. Each log was identified with tree number and position within the tree. This tree-log identification was maintained throughout the scaling and sawing phases of the study.

Wood Deterioration Estimate

After the subsample of trees selected for decay and fungal evaluation were felled, the following data were collected for each tree:

1. Total height (ground line to tip, nearest foot).
2. Mean diameter inside bark (nearest inch) at stump and top of each log.
3. Mean diameter of sap rot (if in pockets) at stump and top of each log.
4. Mean diameter of heartwood (Douglas-fir only) at stump and top of each log.
5. Mean diameter of sound wood (undecayed wood) at stump and top of each log.
6. Mean diameter of heart rot (internal decay) at stump and top of each log.

The cubic foot volume of each tree, of sap rot, of heart rot, of heartwood, and of sound wood remaining was determined by using Smalian's formula,
$volume = (A + a)/ 2 \quad L$,

where: A = basal area at large end of log,

a = basal area at small end of log, and

L = log length.

The sap rot, heart rot, heartwood, sound, and total volumes were calculated for each log. The volume for each tree is the sum of each log in the tree. The volume of sap rot was calculated directly or as the total volume minus the sound volume and any internal decay (if present). No deduction was given for defects such as cracks, checks, or shake in this portion of the study.

Samples of fungi (primarily Hymenomycetes) were systematically collected from each log as follows: a 2-inch thick stem disk was removed from the larger end of each log with a chain saw. A pie-shaped sample of wood (pith to bark) containing stain or decay, if present, was removed from each disk. If no sap rot was present in a tree, then samples from only two disks per tree were taken. Each wood sample was labeled by log and tree number, placed in a plastic bag, transported to the laboratory, and refrigerated until processing.

In the laboratory, each wood sample was aseptically split. Five wood chips (0.2 by 0.2 by 0.4 inch) were aseptically removed from pith to cambium with a wood gouge and labeled as to position (1=bark, 5=pith). The type of wood tissue (clear, stained, decayed) was recorded for each wood chip. Chips were placed onto 2 percent malt agar in culture tubes, one chip per tube. All culture tubes were incubated in the dark at room temperature, and all fungi identified to species, if possible, by using appropriate taxonomic keys and techniques. The results are displayed in tables 2 and 3.

Species of bark beetles were collected from wood samples, placed in vials of ethanol, and identified from appropriate taxonomic keys.

Scaling and Log Grading

In the mill yard, the logs were rolled out for a woods length “as presented” scaling. Scaling was done by using both Scribner (USDA Forest Service 1985) and cubic rules (USDA Forest Service 1991). Each defect was identified by type so that it was possible to separate existing defects from defects related to the death of the tree, such as sap rot and weather check. Next, the logs were bucked into mill sawing lengths of 16 to 20 feet and scaled as mill-length logs by using the same scaling systems. The inland Douglas-fir saw-log grading system (Lane 1964) also was applied to the mill-length logs.

Sawing

The study logs were sawn at a small sawmill in eastern Oregon whose equipment consisted of a circular saw headrig, board edger, and chain saw for trimming rough board ends. Items produced were 2-inch dimension lumber from 4 to 12 inches wide, 3-and 4-inch thick planks 12 inches wide, heavy timbers from 8 by 8 to 12 by 12 inches, and occasional 4/4-inch boards. The lumber was graded by a certified Western Wood Products Association (WWPA) grader in rough green condition according to the following sections from the grading rule book (WWPA 1988):

Lumber item	WWPA rule
1-inch-thick, 4- to 12-inch-wide boards	Commons
1- to 2-inch-thick, 4- to 12-inch-wide selects	Select grades
2 inches thick, 4 inches wide	Structural light framing
2 to 4 inches thick, 6 to 12 inches wide	Structural joists and planks
5 inches and thicker, 5 to 16 inches wide	Beams and stringers

Table 2—Frequency of clear wood, decay, and stain in wood chips of Douglas-fir killed by bark beetles in northeastern Oregon, by years dead and bole position

		Bole position[b]											
Chip	Years	Stump			First			Second			Average		
position[a]	dead	C[c]	S[c]	D[c]	C	S	D	C	S	D	C	S	D
		Percent											
1	0	97.1	0	2.9	100.0	0	0	100.0	0	0	99.0	0	1.0
	2	23.5	47.1	29.4	76.5	5.9	17.7	92.9	0	7.1	64.3	17.6	18.1
	3	37.5	21.9	40.6	53.1	0	46.9	74.1	3.7	22.2	54.9	8.5	36.6
	4	33.3	10.0	56.7	73.3	0	26.7	76.0	4.0	20.0	60.9	4.7	34.4
2	0	97.1	0	2.9	100.0	0	0	100.0	0	0	99.0	0	1.0
	2	76.5	11.8	11.8	94.1	0	5.9	92.9	0	7.1	87.8	3.9	8.3
	3	90.6	3.1	6.3	78.1	0	21.9	88.9	0	11.1	85.9	1.0	13.1
	4	80.0	0	20.0	93.3	0	6.7	80.0	0	20.0	84.4	0	15.6
3	0	97.1	0	2.9	100.0	0	0	100.0	0	0	99.0	0	1.0
	2	100.0	0	0	100.0	0	0	100.0	0	0	87.8	0	0
	3	90.6	3.1	6.3	100.0	0	0	100.0	0	0	85.9	1.0	2.1
	4	96.7	0	3.3	100.0	0	0	92.0	0	8.0	84.4	0	3.8
4	0	97.1	0	2.9	100.0	0	0	100.0	0	0	99.0	0	1.0
	2	100.0	0	0	100.0	0	0	100.0	0	0	100.0	0	0
	3	90.6	0	9.4	100.0	0	0	100.0	0	0	96.9	0	3.1
	4	96.7	0	3.3	100.0	0	0	100.0	0	0	98.9	0	1.1
5	0	97.1	0	2.9	100.0	0	0	100.0	0	0	99.0	0	1.0
	2	94.1	0	5.9	100.0	0	0	100.0	0	0	98.0	0	2.0
	3	90.6	0	9.4	100.0	0	0	100.0	0	0	96.9	0	3.1
	4	93.3	0	6.7	100.0	0	0	96.0	0	1.0	96.4	0	3.6
Average	0	97.1	0	2.9	100.0	0	0	100.0	0	0	99.0	0	1.0
	2	78.8	11.8	9.4	94.1	1.2	4.7	97.1	0	2.9	90.0	4.3	5.7
	3	80.0	5.6	14.4	86.3	0	13.8	92.6	0.7	6.7	86.3	2.1	11.6
	4	80.0	2.0	18.0	93.3	0	6.7	88.8	0.8	10.4	87.4	0.9	11.7

[a] Chip position: 1 = bark, 2-4 = between bark and pith of disk, 5 = pith.

[b] Stump = stump disk, first = top of first log, second = top of second log.

[c] C = clear wood, D = decayed wood, S = stained wood.

Table 3—Frequency of clear wood, decay, and stain in wood chips of grand fir killed by bark beetles in northeastern Oregon, by years dead and bole position

		Bole position[b]											
Chip	Years	Stump			First			Second			Average		
position[a]	dead	C[c]	S[c]	D[c]	C	S	D	C	S	D	C	S	D
		Percent											
1	0	86.2	0	13.8	75.9	6.9	17.2	77.3	13.6	9.1	79.8	6.8	13.4
	3	74.3	0	25.7	37.1	2.9	60.0	63.3	3.3	33.3	58.3	2.1	39.7
	4	23.8	4.8	71.4	19.1	4.8	76.2	50.0	5.6	44.4	31.0	5.0	64.0
2	0	86.2	6.9	6.9	82.8	3.5	13.8	81.8	9.1	9.1	83.6	6.5	9.9
	3	85.7	0	14.3	45.7	2.9	51.4	63.3	3.3	33.3	64.9	2.1	33.0
	4	33.3	4.8	61.9	33.3	4.8	61.9	55.6	0	44.4	40.7	3.2	56.1
3	0	93.1	3.5	3.5	89.6	6.9	3.5	81.8	9.1	9.1	88.2	6.5	5.3
	3	88.6	0	11.4	77.1	2.9	20.0	66.7	0	33.3	77.5	1.0	21.6
	4	52.4	4.8	42.9	61.9	9.5	28.6	55.6	5.6	38.4	56.6	6.6	36.6
4	0	89.7	3.5	6.9	93.1	3.5	3.5	95.5	4.5	0	92.7	3.8	3.5
	3	85.7	0	14.3	71.4	2.9	25.7	80.0	0	20.0	79.0	1.0	20.0
	4	61.9	4.8	33.3	66.7	4.8	28.6	72.2	0	27.8	66.9	3.2	29.9
5	0	86.2	3.5	10.3	86.2	6.9	6.9	90.9	9.1	0	87.8	6.5	5.7
	3	85.7	0	14.3	88.6	0	11.4	96.7	0	3.3	90.3	0	9.7
	4	61.9	4.8	33.3	76.2	0	23.8	77.8	5.6	16.7	72.0	3.4	24.6
Average	0	88.3	3.5	8.3	85.5	5.5	9.0	85.4	9.1	5.5	86.4	6.0	7.6
	3	84.0	0	16.0	64.0	2.3	33.7	74.0	1.3	24.7	74.0	1.2	24.8
	4	46.7	4.8	48.6	51.4	4.8	43.8	62.2	3.3	34.3	53.4	4.3	42.2

[a] Chip position: 1 = bark, 2-4 = between bark and pith of disk, 5 = pith.

[b] Stump = stump disk, first = top of first log, second = top of second log.

[c] C = clear wood, D = decayed wood, S = stained wood.

Lumber Pricing

Lumber and log values were calculated by applying prices from the WWPA (1993) to the volume and grade of lumber produced for each log. Lumber grade groupings were made by combining products of approximately equal value. Lumber grade groupings and prices used were as follows:

Grade group	Lumber grades included	Average value per thousand board feet	
		Douglas-fir	Grand fir
Select structural	D & better selects and Select Structural grade dimension lumber	570.38	532.31
Construction	2 & better common and Construction grade dimension lumber	436.72	447.61
Standard	3 common and Standard grade dimension lumber	412.53	428.81
Utility	4 common and Utility grade dimension lumber	267.61	250.15
Economy	5 common and Economy grade dimension lumber	172.30	169.69

Analysis

This study was conducted to provide (1) volume and value recovery information for live and beetle-killed Douglas-fir and grand fir, (2) information on what changes occur in volume and value in dead trees over time, and (3) identification of biotic agents responsible for deterioration of Douglas-fir and grand fir.

The variables used in analyzing objectives 1 and 2 were lumber volume recovery and grade, and value recovery of lumber or logs. The sources of variation used to analyze the data were log diameter, log grade, and number of years dead. Standard regression techniques were used, and the best model form for each dependent variable was chosen by using the coefficient of determination (R^2) and standard error of the estimate as criteria. Separate regression equations were estimated for live Douglas-fir and grand fir and for each year since death, and a covariance analysis or analysis of variance was done to test for differences among these. Deterioration class samples were combined when no differences were found. All test results were evaluated at the 0.05 probability level.

Model forms tested were:

volume or value $= b_o + b_1D$,

$= b_o + b_1 1/D$,

$= b_o + b_1D + b_2 1/D$,

$= b_o + b_1D + b_2 1/D^2$, and

$= b_o + b_1D + b_2 1/D + b_3 1/D^2$.

Volume Recovery

Lumber volume recovery was analyzed by using cubic recovery percent (CR%), lumber recovery factor (LRF), and overrun. Cubic recovery percent is the volume of rough green lumber expressed as a percentage of log volume. Lumber recovery factor is the number of board feet of lumber recovered per cubic foot of log. Overrun is the ratio of board foot lumber tally to board foot net Scribner scale. Prediction models using CR%, LRF, and overrun as dependent variables were tested by using log small-end diameter and transformations thereof as independent variables.

In addition, estimates of volume loss related to sap rot and weather check were made for each class of dead logs. Log scale estimates of defect and their relation to lumber volume loss were analyzed for the noncull and cull logs (logs less than one-third sound). A technique using bias and accuracy estimates was used to evaluate the effectiveness of the scaling defects (Fahey and others 1981). This technique compares the recovery of defective logs with sound logs of equivalent volume. The yield of lumber from sound logs was established by regressing lumber volume over gross cubic log volume. With this regression line for sound logs as a base, the loss in lumber tally for each defective log is the actual lumber tally minus the predicted lumber tally for the net scale volume of the log. To evaluate the effect of a single defect, such as sap rot, the sample was separated into logs with multiple defects, only sap rot, and only weather check. Bias and accuracy were calculated for each defect sample, species, and deterioration class.

Value Recovery

Two variables will be used to express value recovery: dollars per thousand board feet of lumber tally ($/MLT) and dollars per hundred cubic feet of gross log volume ($/CCF). Dollars per thousand board feet of lumber tally represents the average value of the lumber produced from the log. Dollars per hundred cubic feet represents the value of the log including differences due to the amount of lumber that can be recovered, which is affected by the amount and type of defect.

The percentage of lumber volume recovery by product grade groupings also will be estimated by deterioration classes. Prediction formulas for the percentage of lumber volume will be additive for all lumber grade groupings.

Decay Volumes

Analysis of variance (NPAR1WAY procedure; SAS 1987) was used to determine significant ($P<0.05$) differences in percentage of sap rot volume among tree mortality classes (three or four) and tree diameter classes (four).

Results and Discussion

Decay and Fungi

Of the 117 Douglas-fir and 87 grand fir trees sampled in this portion of the study, total age averaged 161 and 121 years, d.b.h. averaged 20 and 19 inches, and total height averaged 90 and 89 feet, respectively. Sap rot increased significantly ($p = 0.0001$ [Douglas-fir] and 0.0003 [grand fir]) with years dead, but there were no significant differences in sap rot among d.b.h. classes, probably because of the dry weather conditions. The following tabulation shows the increase in percentage of sap rot for trees as time-since-death increases:

Species	Percentage of sap rot by years dead[2]			
	0	2	3	4
	Percent			
Douglas-fir	0 (35)	1.0 (18)	8.1 (33)	11.4 (31)
Grand fir	0 (30)	—	1.7 (36)	8.0 (21)

Three years after bark beetle-caused mortality, Douglas-fir had 8.1 percent sap rot and grand fir had 1.7 percent. In a west-side study of Douglas-fir killed by bark beetles, 15 percent of the total cubic volume had sap rot after 3 years (Wright and Wright 1954). Sapwood in Douglas-fir averaged 39.4 percent in our present east-side study and was 22 percent in the earlier west-side study (Wright and Wright 1954). Because the east-side trees had a greater proportion of sapwood than did the west-side trees sampled, they should have had a higher percentage of sap rot. It also was surprising that Douglas-fir had more sap rot than grand fir, because grand fir is generally considered more decay prone. Perhaps differences in deterioration rates occurred because the sampled Douglas-fir and grand fir were from different sites. Another possible explanation is that attacks by the Douglas-fir beetle (and vector spores) were much greater than attacks by the fir engraver, thereby resulting in more decay in Douglas-fir than in grand fir.[3]

We speculate that the extremely dry conditions over the duration of the study were not conducive to wood decay in either species. Although conks of *Cryptoporus volvatus* were present on almost all dead trees of both species, relatively little decay had gone beyond the inner bark. Relative moisture contents of wood samples collected in June 1993 averaged 53.7 percent for stump disks, 33.0 percent for disks at midbole, and 29.8 percent at the upper portions of trees. This is sufficient moisture to allow decay (Boyce 1961), but winter and spring of 1992-93 were wetter than the average for the previous 3 years. Also, wood moisture content may have been much lower throughout summer and fall. During winter, when precipitation is greatest, temperatures are generally too low in northeastern Oregon for decay to occur.

In addition to the dry climatic and soil conditions, study trees sustained several consecutive years of spruce budworm defoliation of current year foliage and had a much reduced complement of mostly old needles before they died. Because older foliage is less active in both photosynthesis and transpiration (Lassoie and others 1985), the crown condition may have contributed to a gradual overall reduction of uptake and storage of water in the bole.

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[2] Number in parentheses is the number of trees sampled.

[3] Personal communication. 1995. Craig Schmitt, Zone Pathologist, Blue Mountains Pest Management Zone, Wallowa-Whitman National Forest, 1401 Gekeler Lane, La Grande, OR 97850.

Table 4— Percentage of scaling defect by defect type and deterioration class for live and dead Douglas-fir and grand fir logs

Species and deterioration class	Cubic scaling deductions			
	Cull logs	Existing defect	Sap rot	Weather check
	Percent			
Douglas-fir:				
Live	1.5	4	0	0
1-year dead	3	3	6	1
2-year dead	10	4	13	3
3-year dead	23	4	27	4
4-year dead	21	4	20	5
Grand fir:				
Live	5	4	0	0
1-year dead	8	5	10	3
3-year dead	43	6	18	6
4-year dead	39	3	21	5

Most of the decay was caused by *Cryptoporus volvatus*, and most of the isolations of decay fungi were of that fungus, which is not surprising considering the abundance of conks. No other species of conks were found, even in trees dead for 4 years. This differs from the west-side study where conks of *Fomitopsis pinicola* were often present on trees dead for 2 years or more (Wright and Wright 1954). Frequency of decay in wood chips used for recovering microorganisms tended to increase with years dead, as expected, for both tree species (tables 4 and 5). Frequency of decay in wood chips tended to decrease from stump to tree top and toward the center of a log. There was a higher frequency of decayed wood chips in grand fir than in Douglas-fir at 0, 3, and 4 years dead, which differed from our earlier finding that Douglas-fir had more sap rot than did grand fir.

Only four wood samples contained insects, and these were two samples with larvae of Buprestids in Douglas-fir and two samples with larvae of Cerambycids in grand fir. Wright and Harvey (1967) also report only minor damage from wood borers for about the first five years. They also report, however, that the sapwood of Douglas-fir was extensively decayed in their west-side study by year 5.

Volume Recovery

The volume of product that can be produced from standing timber is impacted by losses in the felling and yarding process, losses from existing defect and defect associated with the death of the trees, and losses associated with turning round logs into rectangular lumber. The following sections will provide information on these three aspects for both the live and dead samples.

Table 5—Bias and accuracy results for evaluation of the effectiveness of cubic scaling rules

Defect and species	Number of logs	Average gross volume	Bias	Accuracy	Average bias[a]
		– – – *Cubic feet* – – –			*Percent*
Noncull logs:					
Sap rot—					
Douglas-fir	161	15.4	1.1	2.2	7.1
Grand fir	68	14.8	2.6	3.8	17.6
Weather check—					
Douglas-fir	45	9.2	.2	1.2	2.2
Grand fir	22	10.0	.8	1.6	8.0
Multiple defects—					
Douglas-fir	218	19.5	1.1	2.9	5.6
Grand fir	133	22.2	1.9	3.5	8.6
Cull logs					
Sap rot—					
Douglas-fir	31	5.9	1.3	1.4	22.0
Grand fir	43	9.3	2.0	3.0	21.5
Weather check—					
Douglas-fir	10	3.5	.7	.9	20.0
Grand fir	12	4.3	1.3	1.6	30.2
Multiple defects—					
Douglas-fir	49	11.7	1.4	3.4	12.0
Grand fir	56	16.5	6.4	10.1	38.8

[a] Average bias expressed as a percentage of log volume.

Breakage during falling and skidding generally increases in dead timber. Breakage in the live samples was less than 0.5 percent of the gross volume of the trees, based on measurements taken after felling. The breakage and amount of wood too defective to remove from the woods was about 2.5 percent in dead Douglas-fir and 3.8 percent in dead grand fir. These percentages did not change significantly as time since death increased, and they reflect the logging conditions (flat ground) and harvesting systems (ground-based equipment) used for this study.

Estimated losses from existing defects in the live sample were roughly 4 percent for both Douglas-fir and grand fir. In both species, the primary cause of volume loss because of death was sap rot and weather checks. Most sap rot occurred on the lower logs, while in the upper portions of the boles there was extensive loss due to weather checking caused by drying. Figure 1 shows the relation between log size and cubic scaling defect percentage for weather check. No relation with diameter was found for the other defects. Table 4 shows the percentage of logs culled and the estimated amounts of cubic scaling defect from the noncull portion of the sample. The existing defect was fairly consistent throughout the sample. There are two reasons for the differences in sap rot percentages between the previous section and this one: (1) one is based on trees and the other on logs; and (2) one was a more precise measurement of diameter affected, and the other is based on scaling rules designed to estimate the amount of volume available to produce lumber.

The analysis of the relation between the log scaling deduction and the lumber loss showed that defect estimation was reasonably unbiased and accurate (table 5). No difference in bias and accuracy was found among the deterioration classes, so the results were combined. Compared to previous tests of defect (Cahill and Cegelka 1989), the results of this study showed about half the bias for the weather check and the soft rot. In general, the deductions seem to be effective in predicting the loss in lumber volume with the exception of the sap rot deductions for grand fir. The scalers commented that this deduction was particularly difficult because the defect was in scattered pockets rather than throughout the entire sapwood. A positive bias indicates an overestimation of the defect; the estimate for grand fir was generally more biased than that for Douglas-fir for all defects.

Cull logs present a special category of logs that are judged by scalers to have less than one-third of the volume available for lumber production, and they may or may not contain merchantable volume (USDA 1985). In this study, some cull logs were left in the woods because they were too rotten to load on the truck, some were brought to the mill yard but not sawn because they were too rotten to hold together on the headrig, and some were sawn and produced lumber volume. Almost twice as many grand fir logs were culled compared to Douglas-fir (table 4), and roughly half of the culls for each species were sawn in the mill. The defect deductions for the cull logs were very biased (table 5), which shows that more lumber is recovered from the logs than the net scale predicts; however, this is just an evaluation of how much lumber is recovered and does not take into consideration the quality or value of that lumber.

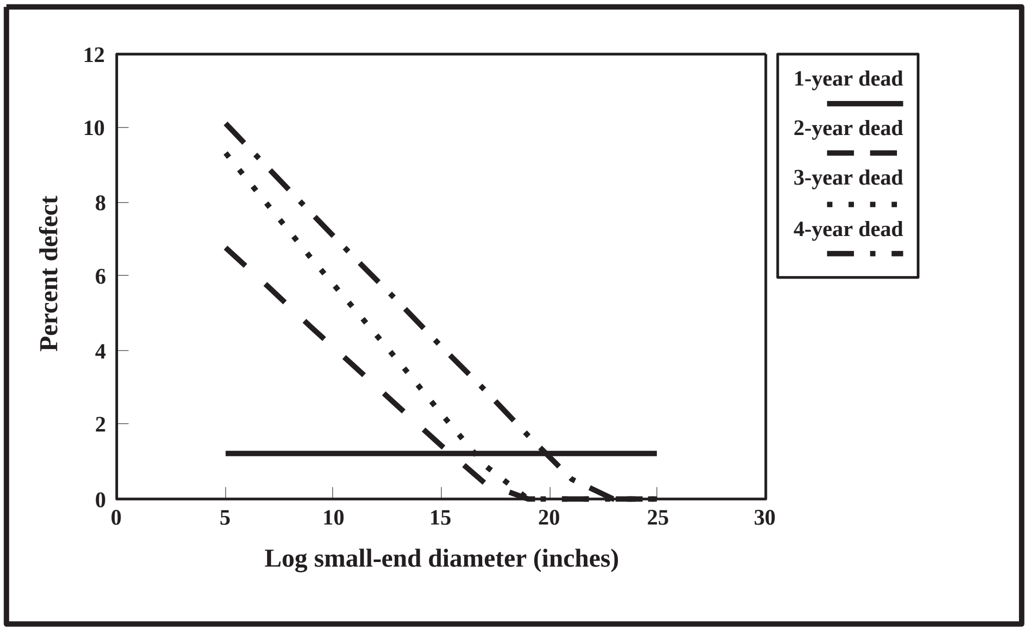

Figure 1—Log scaling deductions for weather check are shown for the Douglas-fir sample. Weather checks are found primarily in the upper portions of the trees. The volume deducted decreases as log diameter increases, and increases with time since death.

Cubic recovery percent—The most accurate way of measuring product volume recovered from a log is CR% because it uses cubic volume for both lumber and log. Analysis of CR% was done by using gross cubic scale, by deterioration class, with cull logs analyzed as a separate sample. Results of the covariance analysis showed no significant differences between the two samples of live logs by species and the 1-year-dead Douglas-fir sample. No significant difference was found between the dead samples for grand fir and the 2-year-dead sample of Douglas-fir. Finally, no difference was found between the 3- and 4-year-dead Douglas-fir samples. Therefore the results will be presented for the following deterioration classes:

Class	Species	Years since death
Live	Douglas-fir	Live
	Grand fir	Live
	Douglas-fir	1 year
GFVol	Grand fir	1 year
	Grand fir	3 years
	Grand fir	4 years
	Douglas-fir	2 years
DFVol	Douglas-fir	3 years
	Douglas-fir	4 years

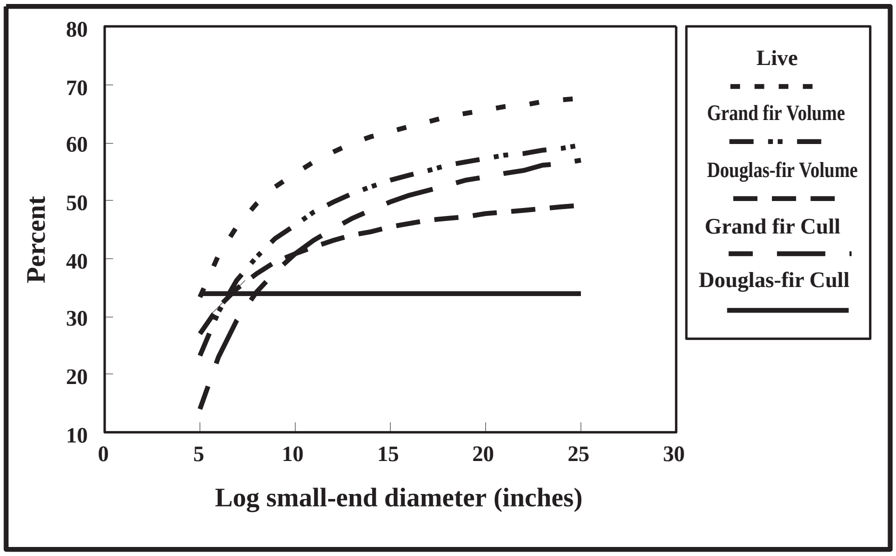

Figure 2—Cubic recovery percent is greatest for the live sample and is reduced by 10 to 15 percent for grand fir and Douglas-fir samples. Cubic recovery percent is lowest for cull logs from all samples. Regression equations and statistics are found in table 6.

The change in recovery volume that takes place as a tree changes from live to dead is clearly illustrated in figure 2. Regression equations and statistics are found in table 6. The volume of lumber recovered is different between samples of dead grand fir and Douglas-fir. With Douglas-fir, very little volume is lost in the first year after death, so the 1-year-dead sample was combined with the live sample. Two-year-dead Douglas-fir recovered about 8 percent less volume than live and 1-year dead, the same as all classes of grand fir dead. Three-and four-year dead, combined, lost another 7 percent volume. Cubic recovery percent of cull logs is also shown in figure 2. The Douglas-fir cull logs recovered 34 percent of the log volume as lumber, but the grand fir cull logs larger than 10 inches recovered more lumber than the 3- and 4-year-dead Douglas-fir and only slightly less volume than the dead samples of grand fir. This follows the earlier finding that the amount of defect in the grand fir is difficult to estimate, and in this study, the deductions were not well correlated with the actual volume of lumber lost. It is important to remember that this reflects only the amount of lumber that is produced and not the quality of that lumber.

Lumber recovery factor—Lumber recovery factor (LRF) is a measure of the number of board feet of lumber that can be produced from a cubic foot of log. As with CR%, it is based on the gross cubic-foot scale volume of the logs. In this study, the ratio between the board foot of lumber and the cubic foot of lumber (BF/CF) was consistently 11.8. It is therefore possible to convert the CR% given in figure 2 directly into LRF as follows: CR%   BF/CF of lumber = LRF. For example, a 10-inch live log has a CR% of 54.8 percent, which is multiplied by the BF/CF of 11.8, resulting in an LRF of 6.47.

Overrun—Overrun is the term for the percentage of lumber recovered by a sawmill in relation to the log scaler's estimated amount of volume (net Scribner scale). Scribner scale does not take taper into consideration and typically is highly inaccurate in estimating net scale when used for measurement of dead timber (Snellgrove and Cahill 1980). No significant relation was found between overrun and small-end diameter, so averages were calculated for each of the combined classes as follows: average overrun for the Douglas-fir live, Douglas-fir 1-year dead, and grand fir live samples was

Table 6— Regression equations and statistics for estimates of volume recovery

Dependent variable	Equation	R^2	MSE[a]
	Cubic recovery percent of rough green lumber volume		
Live	76.18-212.71/D	0.4544	10.45
GFVol	68.01-218.50/D	0.2912	10.55
DFVol	54.64-138.39/D	0.1900	10.10
Douglas-fir cull	40.59-64.00/D	0.0403	14.52
Grand fir cull	45.63 (mean)	0.3165	12.95
	Dollars/1000 lumber tally		
Live	328.62+6.76*D	0.2006	64.63
GFVal	237.68+10.79*D	0.3340	54.92
DFVal	279.75+5.05*D	0.0900	66.68
Douglas-fir cull	279.97 (mean)	0.0000	80.55
Grand fir cull	342.49-0.84*D	0.0000	59.03
	Dollars/100 cubic feet of gross log volume		
Live	417.79-1454.97/D	0.3988	80.09
GFVal	396.05-2018.79/D	0.4440	60.56
DFVal	253.38-803.23/D	0.1794	61.40
Douglas-fir cull	145.51-306.79/D	0.0576	57.72
Grand fir cull	179.60 (mean)	0.2202	60.55

[a]MSE=Total mean squared error of the regression model.

140 percent; average overrun for the combined 2- to 4-year dead Douglas-fir samples was 166 percent, and 185 percent for combined grand fir dead samples; average overrun for the cull samples was 203 percent for Douglas-fir and 506 percent for grand fir. It is apparent that the scaling rules again over-deducted for the defects, thereby causing the overrun to increase in the dead samples, especially for grand fir.

Value Recovery

Dollars per thousand lumber tally—Dollars per thousand lumber tally ($/MLT) is the most accurate measure of the inherent wood quality, because it is based only on the lumber that is produced and does not include estimates of defect. It was used to test the inland Douglas-fir saw-log grades to see if they segregate the value of the resource. Analysis of $/MLT showed no statistical difference among the grades; thus, log grades were not used in further analysis. Dollars per thousand lumber tally was then used to test for differences among deterioration classes. Similar to the CR% results, no difference was detected between the live samples and the 1-year dead Douglas-fir sample, and no difference was found among the samples of dead grand fir. A slightly different result was found with the dead Douglas-fir samples, in that the 2-year dead was found to not be different from the 3- and 4-year-dead samples. Two additional deterioration classes therefore were established: GFVal, which includes all years of grand-fir dead; and DFVal, which includes years 2 through 4 of Douglas-fir dead. Regression equations and statistics are found in table 6.

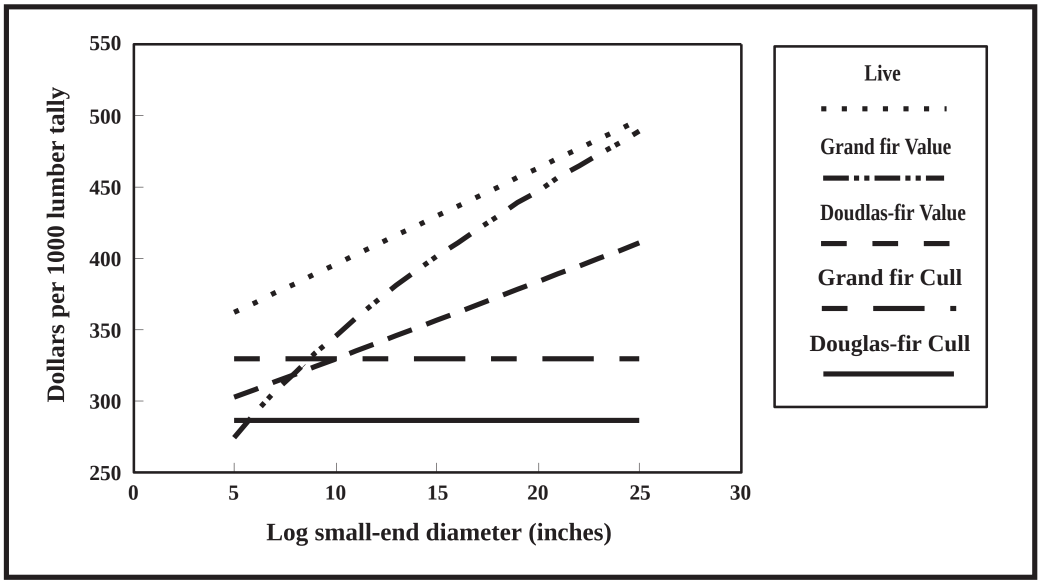

Figure 3—Dollars per thousand lumber tally increased with increasing diameter because there was more opportunity to recover higher grade lumber and larger size lumber from larger logs. Average lumber value of the cull logs reflects the increased volumes of Economy and Utility grade lumber produced.

Dollars per thousand lumber tally increased with increasing diameter (fig. 3) because there was more opportunity to recover higher grade lumber and also larger size lumber from larger logs. Douglas-fir live and 1-year-dead logs were worth about $70 per thousand more than 2-, 3-, and 4- year-dead logs for all diameters. The grand fir dead sample produced lumber that was $100 less valuable than the live sample for logs with 5-inch diameters compared to logs with relatively no difference from the live in the larger diameters. Average lumber value of the cull logs reflected the large increase in Economy and Utility lumber that is produced from these logs.

Percentage of lumber volume by lumber grade—Percentage of lumber volume produced by lumber grade can help to explain changes in value recovery over diameter and deterioration class. Lumber grade recovery is presented in figure 4 and table 7 for the combinations of deterioration classes that were determined by analysis of $/MLT. In both species, Select Structural grades were produced in low volume (less than 10 percent). For Douglas-fir there was a 3-percent decrease in production of Select Structural from live trees compared to the 2-to 4-year-dead class. Production of Standard lumber dropped 17 percent when trees left standing for 2 years were compared to live trees. Production of Utility grade lumber in the 2-year and older dead class was more than double that from live trees. Grand fir grade recovery was more dramatically affected by death of the tree. As shown in figure 4, Construction grade lumber production falls off drastically after the tree dies. The amount of Construction grade lumber available from all years of dead was less than one-half that from live trees. Utility grades showed an increase, jumping from 14 to 24 percent when sawn from 1-year-dead timber vs. live. The volume recovered from Economy was relatively minor but followed the trend of Utility to increase in volume share after the tree was dead a few years. Cull logs of both species produced very little Select Structural or Construction grade material. The Douglas-fir cull sample produced 40 percent Economy and 27 percent Utility lumber. The grand fir cull sample, on the other hand, produced less than 20 percent Economy and about 40 percent Utility.

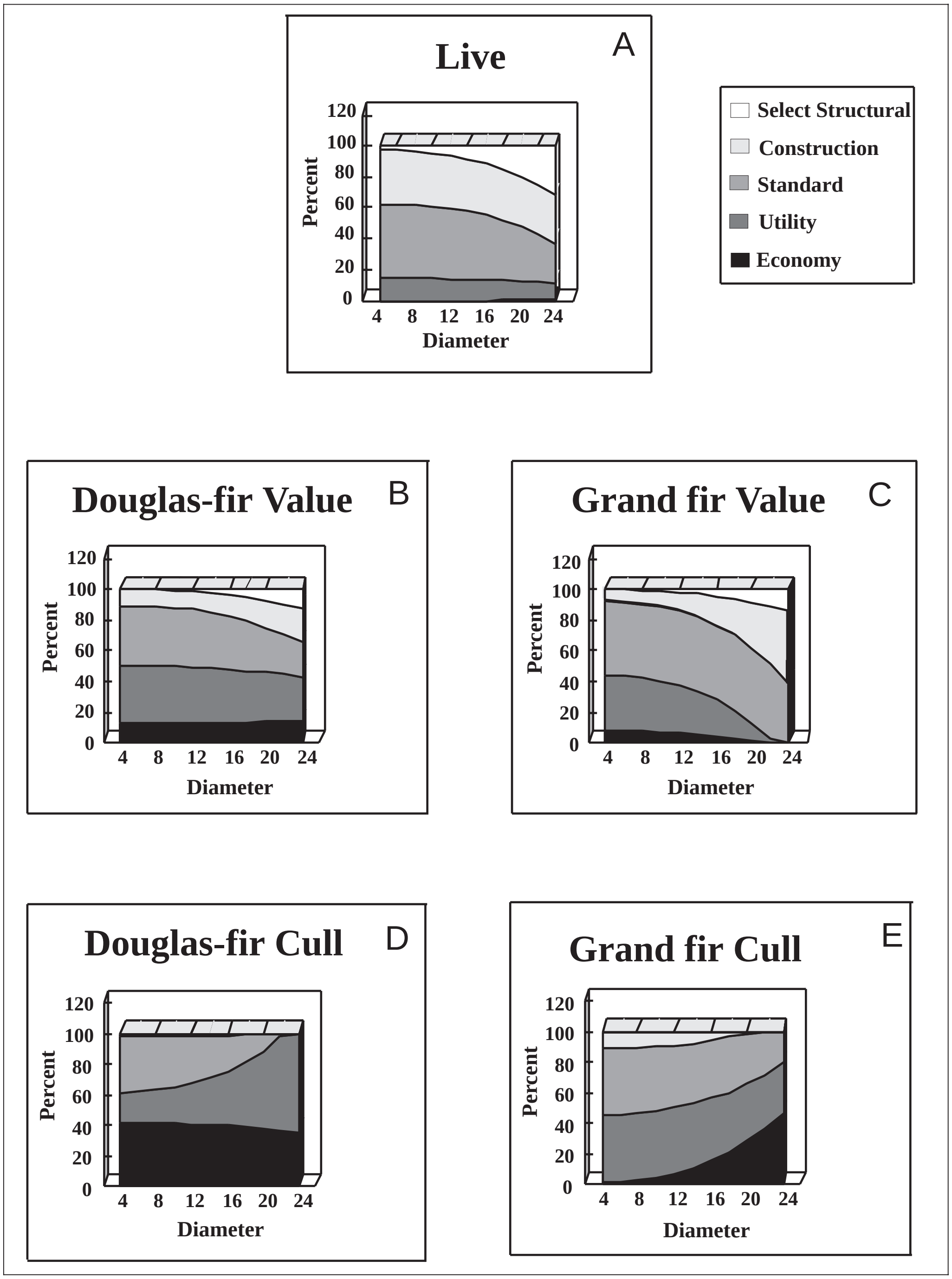

Figure 4—Percentage of lumber volume by lumber grade illustrates the differences in value among the live, dead, and cull samples of logs. **A.** Production of Construction and Select Structural grade lumber was highest for the live log sample. **B.** Volume of Utility grade lumber doubles and Construction grade decreases in the Douglas-fir dead sample (DF Value) compared with the live sample. **C.** The volume of Select Structural and Construction decreased by 50 percent and volume of Utility doubled in the grand fir dead sample (GF Value) compared with the live sample. **D.** Sixty to ninety percent of the volume of the Douglas-fir cull log sample was graded as Utility or Economy. **E.** The grand fir cull log sample produced much less Economy and Utility than did the Douglas-fir cull log sample but significantly more than the grand fir dead sample.

Table 7—Percentage of lumber volume by species, lumber grade group, and years since death

Species and lumber grade group	Live	Years dead 1	2	3	4	Cull logs
	Percent					
Douglas-fir:						
Select structural	5	4	2	2	2	0
Construction	20	15	13	12	13	2
Standard	55	46	38	37	34	30
Utility	16	30	37	38	33	27
Economy	4	5	10	12	17	40
Grand fir:						
Select structural	8	4	—	1	3	0
Construction	34	17	—	16	11	7
Standard	43	49	—	50	46	39
Utility	14	24	—	29	34	42
Economy	0	6	—	5	7	12

Dollars per hundred cubic feet—Dollars per hundred cubic feet of gross scale is an estimate of the value of the log, including the defect. For the combined live samples and the 1-year-dead Douglas-fir sample, the $/CCF increased rapidly in the smaller diameters and then began to level off in the larger diameters (fig. 5). This correlates with the increased output of construction and higher grade dimension products. In the 2- to 4-year-dead Douglas-fir class, the value increased more gradually with increases in log size. Economy and Utility production stayed about the same with increasing diameter, Standard grade lumber decreased slightly, and Construction and Select Structural grade increased, but only slightly. The combined effect was a very gradual increase in value as log diameter increased in the 2- to 4-year-dead class. The grand fir combined dead sample increased in value at the same rate as the live samples when diameter increased. The cull log samples had lower values than any of the live or dead classes. The Douglas-fir cull sample was considerably lower in value than any other sample, but the grand fir cull was closer to the value of the dead Douglas-fir class. This reflected the higher volume recovery but lower quality of the lumber for grand fir.

Conclusions

The amount of sap rot, caused principally by *Cryptoporus volvatus*, was relatively low in Douglas-fir and grand fir, especially when compared to west-side decay rates (Wright and Wright 1954). The amount of checking was very high, probably due to several years of drought after tree death. Sap rot and especially checking increased with time since tree death. Few insects were associated with defective wood, probably because of the relatively dry condition of the wood.

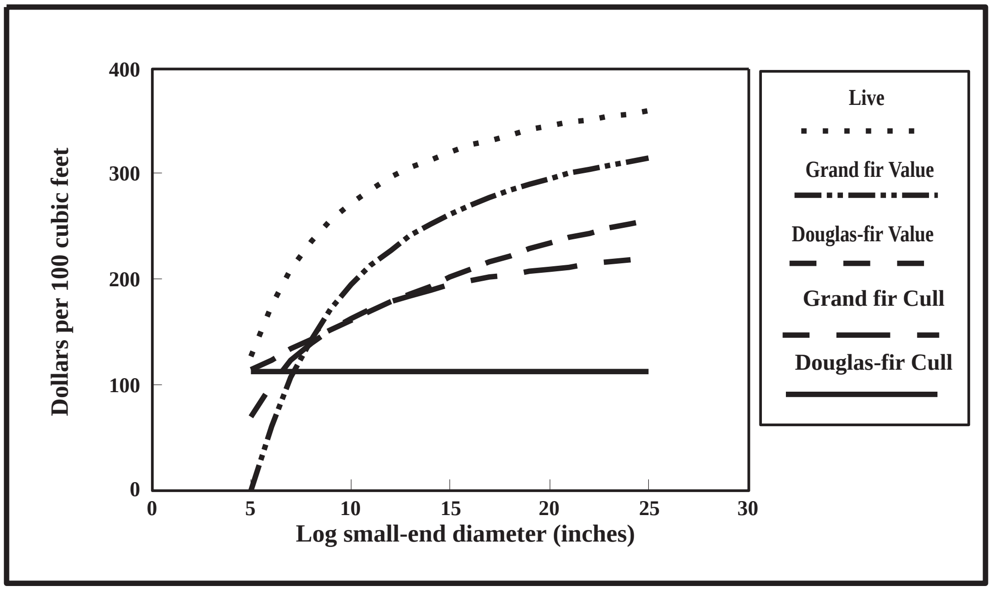

Figure 5—Dollars per hundred cubic feet of gross scale is an estimate of the value of the log, including the defect. The grand fir dead sample was $70 per hundred cubic feet less in value than the live sample. The Douglas-fir dead sample was $60 per hundred cubic feet less in value than the grand fir dead sample. Dollars per hundred cubic feet is lowest for cull logs from all samples.

Losses associated with breakage and handling were minor, ranging from 0.5 percent to 3.8 percent for all samples. Existing defect averaged 4 percent for all samples. Weather check increased from 1 to 5 percent and sap rot increased from 6 to 20 percent as time since death increased from 1 to 4 years. Scaling deductions worked fairly well at predicting the lumber volume loss due to defect, except in the grand fir dead samples where the deductions were too severe.

Cubic recovery percent showed no difference between the live samples and the 1-year-dead Douglas-fir sample, so they were combined. The other dead samples were combined into a class for all grand fir dead and Douglas-fir 2-year dead and a class for the Douglas-fir 3- and 4-year dead. There was an 8-percent loss in CR% between the live and grand fir dead classes and a 15-percent loss in CR% between the live and Douglas-fir 3-and 4-year-dead classes.

Analysis of $/MLT and $/CCF showed no difference among the live and 1-year dead Douglas-fir samples. The dead classes shifted slightly with all the Douglas-fir dead (years 2 to 4) being combined and all the grand fir classes being combined. Average log value decreased about $60 from the live class to the grand fir dead class and another $60 for the Douglas-fir dead. Contrary to popular belief, the grand fir did not deteriorate as fast as the Douglas-fir or lose as much value as expected.

Cull logs ranged from 3 to 40 percent of the samples as age since death increased. Only half of these logs were sound enough to process into lumber, but those logs recovered more volume than the scalers anticipated. The Douglas-fir cull logs recovered only 34 percent of the gross volume as lumber, but the grand fir cull sample recovered more lumber than the Douglas-fir 3-and 4-year-dead class and only slightly less than the grand fir dead sample. The lumber that was produced was largely comprised of Economy and Utility grade. The combination of the high volume recovery and low value recovery resulted in log values for the grand fir culls that were only slightly less than those for the Douglas-fir dead class, but the Douglas-fir culls were worth considerably less than any other sample.

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Parry, Dean L.; Filip, Gregory M.; Willits, Susan A.; Parks, Catherine G. 1996. Lumber recovery and deterioration of beetle-killed Douglas-fir and grand fir in the Blue Mountains of eastern Oregon. Gen. Tech. Rep. PNW-GTR-376. Portland, OR: U. S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 24 p.

The purpose of this study was to determine the effect of time since death over a 4-year period on the amount of usable product volume and value, and to determine the species of fungi associated with wood deterioration in the stems of Douglas-fir and grand fir trees killed by bark beetles in northeastern Oregon. Two-year- dead Douglas-fir recovered about 8 percent less lumber volume than live and 1-year dead Douglas-fir and all classes of dead grand fir. Three- and four-year dead Douglas-fir combined lost another 7 percent in lumber volume. Average lumber value (dollars per thousand lumber tally) and average log value (dollars per hundred cubic feet) analysis showed no difference among the live and 1-year-dead Douglas-fir samples. Average log value decreased about $60 from the live class to the grand fir dead class and another $60 for the Douglas-fir dead. Contrary to popular belief, the grand fir did not deteriorate as fast as the Douglas-fir or lose as much value as expected.

Keywords: Douglas-fir, *Pseudotsuga menziesii*, grand fir, *Abies grandis,* lumber recovery, utilization, dead timber, western spruce budworm, *Choristoneura occidentalis* Freeman, Douglas-fir beetle, *Dendroctonus pseudotsugae*, fir engraver, *Cryptoporus volvatus, Trichaptum (Polyporus) abieinum, Fomitopsis pinicola*.

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