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Losses From Decay In Western Hemlock

Abstract

Incidence of infection by decay fungi and losses due to decay were measured in 320 trees from 8 pairs of thinned and unthinned western hemlock stands ranging in age from 46 to 119 years. Decay fungi were recovered from a large number of trees, (41.9 percent of those in thinned and 23.1 percent of those in unthinned stands). However, associated wood loss averaged only 2.8 percent of the gross merchantable cubic foot volume for all stands. Most decay was associated with wounds. No statistically significant differences in growth rates were found between infected and uninfected trees. Decay losses apparently can be kept to fairly low levels, even in stands that are entered frequently, if rotation age is short (120 years or less). Additional wood volume can be saved by minimizing wounding during management treatments and by removing wounded trees during thinning operations.

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Losses From Decay In 40- to 120-Year Old Oregon and Washington Western Hemlock Stands

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Contents

Introduction

Western hemlock [*Tsuga heterophylla* (Raf.) Sarg.] is an extremely important component of second-growth forests in western Oregon, Washington, and British Columbia where it constitutes approximately 25 percent of the total softwood timber resource (1) and is believed to be capable of producing higher yields than Douglas-fir [*Pseudotsuga menziesii* (Mirb.) Franco] on many sites (1, 4, 27, 32). In view of the potential of the species, considerable interest has developed among plant pathologists and land managers concerning susceptibility of western hemlock to decay fungi, especially *Fomes annosus* (Fr.) Cke.

Studies have shown that old-growth western hemlocks (180 years old or older) are highly defective due to decay (3, 8, 9, 11, 12, 33, 34). However, concern today is focused on younger trees. Now, western hemlock stands are being managed on rotations of 40 to 120 years (4) with precommercial and commercial thinning integral parts of their treatment. Evidence suggests that such intensively managed young stands may have high amounts of infection by decay fungi associated with wounding (15, 20, 23, 24, 25, 31) and root contacts between young trees and infected stumps (5, 6, 7, 17, 18, 22, 25, 29, 30). The relationship between the latter type of infection in thinned stands and subsequent spread of *F. annosus* is a matter of particular interest. Since windblown spores of *F. annosus* readily colonize freshly-cut stump surfaces, the creation of large numbers of stump infection courts during thinning operations may lead to substantial disease buildup in managed stands. Potentially, decay fungi could cause large losses in young stands by destroying wood and reducing growth rates.

In the past, studies of decay pathogens in young western hemlock mainly have involved measuring incidence of infection. Statistically analyzable data are lacking on actual losses resulting from decay in such stands. Therefore, the objectives of this evaluation were to (a) determine amount of infection by wood rotting fungi and associated mortality, decay, and growth loss in a sample of 40-to-120-year old stands in Oregon and Washington and (b) compare infection and magnitude of loss between thinned and unthinned stands.

Methods

Eight pairs of stands, each consisting of a thinned and adjacent unthinned stand, were selected for examination. The two stands in each pair were as similar as possible with respect to age and site, and all stands were between 40 and 120 years old (current rotation age). The thinned stands had been thinned commercially at least 10 years before the investigation. A minimum of 10 years was used so that trees would have had a chance to express growth changes that might have resulted from thinning and show effects of any infection by decay fungi that may have been associated with the management activities. Five pairs of stands were located in western Washington and three in northwestern Oregon (Figure 1). Western hemlock was the dominant species in all stands. Other species encountered were Douglas-fir, Sitka spruce [*Picea sitchensis* (Bong.) Carr.], Pacific silver fir [*Abies amabalis* (Lind.) Forbes], and western redcedar [*Thuja plicata* (D. Don.)].Stump evidence suggested that most stands had developed following clearcutting of old-growth stands composed predominantly of western hemlock.

A sampling grid (Figure 2) was established in each stand as follows: a base line was located along the most accessible margin of the stand, and its length was measured. The length obtained was divided by five to determine the distance between the origins of four survey lines. Starting points were located by measuring from an arbitrarily chosen corner of the stand. At those points, survey lines were run at right angles to the base line. Five basal area plots were located at 100 ft. intervals along each line, making a total of 20 basal area plots per stand. A 20 factor prism was used to define each plot in thinned stands and a 40 factor prism was used in unthinned stands. The first "in" western hemlock to the north of each plot center was chosen for intensive sampling and will hereafter be referred to as the sample tree. All other "in" trees were recorded by species and DBH.

The general condition (living or dead) of the sample tree was noted, DBH measured, and crown class determined. Four roots, one each on the sides corresponding to the cardinal compass directions, were uncovered to a distance of 3 ft. from the tree. A 6 in. long section was cut from each root, placed in a plastic bag, and returned to the laboratory. Sections were surface sterilized, split, and 12 wood chips were taken from each and placed on benomyl-malt agar (16) in an attempt to isolate decay organisms. After the chips had been removed, samples were wrapped in moist newspaper, incubated for 10 days to 3 weeks, and examined for evidence of fungi.

Following root excavation, each sample tree was felled. Measurements were taken of total tree height, height to the merchantable top (4 in. diameter), and diameters outside and inside bark at stump height (1.5 ft.), at the top of the first log (40 ft.), and at the merchantable top. The tree was rated for dwarf mistletoe [*Arceuthobium tsugense* (Rosendahl) Jones] infection using Hawksworth's 6-point system (14), and the leader length for the last 10 years was measured. Leaders were dissected to verify age by ring count. Presence of all wounds and conks were noted. Size (length x width x 0.75), age (determined by removing a section from the callus at the wound edge and counting the rings), and location (in butt—lower 6 feet of bole; in stem—above 6 feet) were recorded for each wound. Samples of wood from all butt wounds and a subsample (10 percent) of stem wounds were collected. In the laboratory, isolations were made to identify the fungi colonizing them. Stems with conks were dissected to determine amount of decay.

The term "decay" as used in this evaluation refers to wood that has lost its structural properties and has become soft (Figure 3). Incipient decay or stain in which wood structural properties are not altered appreciably (2) is not presently considered to be a scale

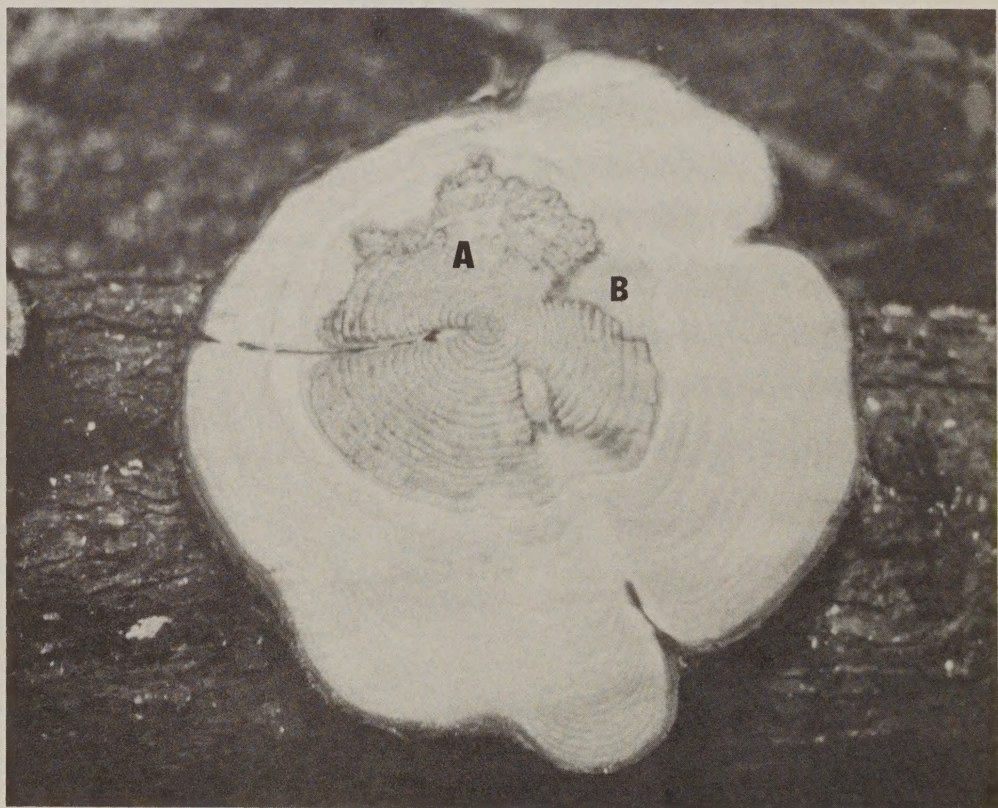

Figure 3. Cross section of western hemlock infected with *Fomes annosus*. Dark area in center (A) is advanced decay while lighter colored area (B) is incipient decay (stain).

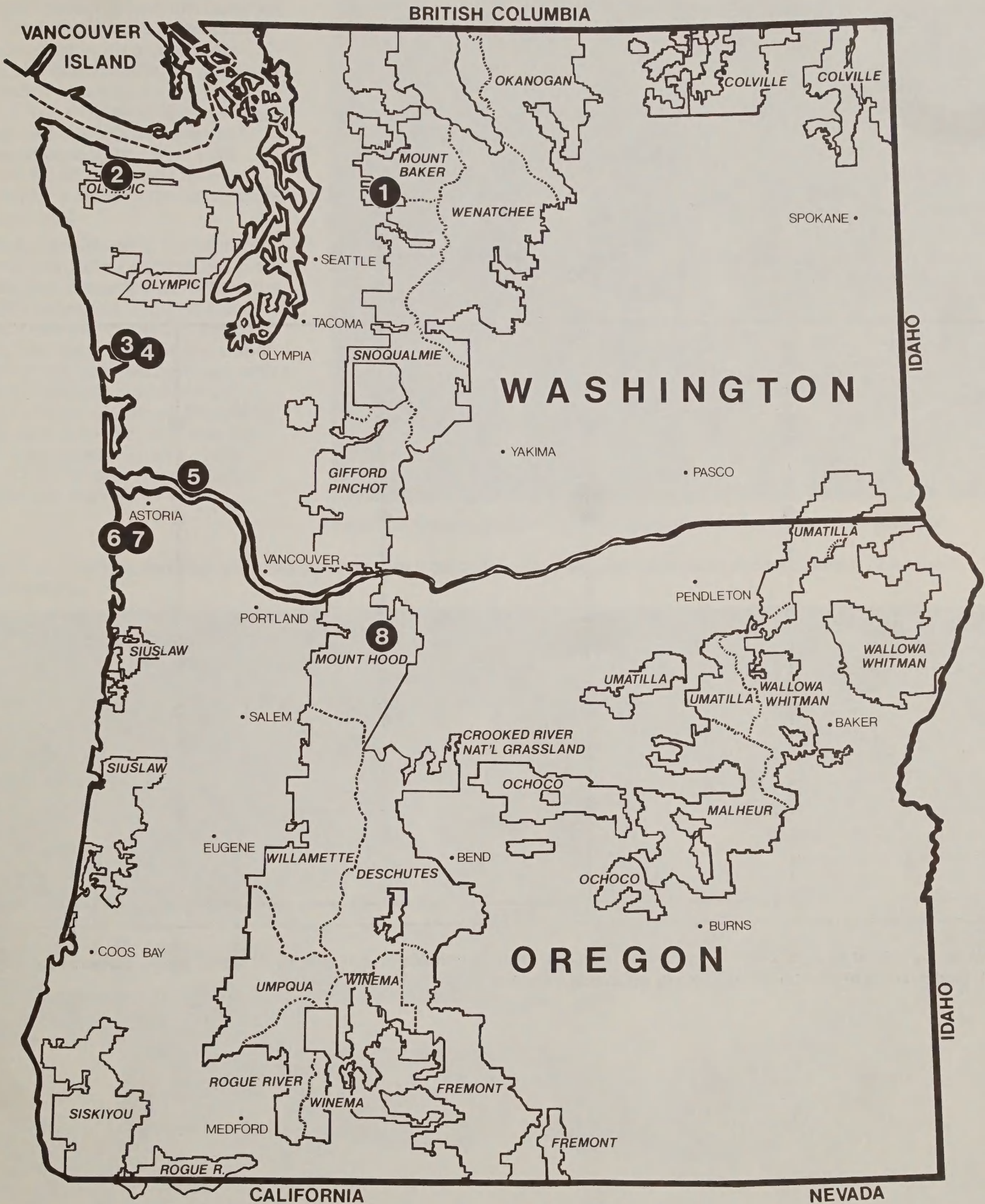

Figure 1. Location of paired stands surveyed in 1978 western hemlock decay evaluation: 1—Verlot, Washington; 2—Forks, Washington; 3 and 4—Aberdeen, Washington; 5—Cathlamet, Washington; 6 and 7—Seaside, Oregon; 8—Bull Run, Oregon.

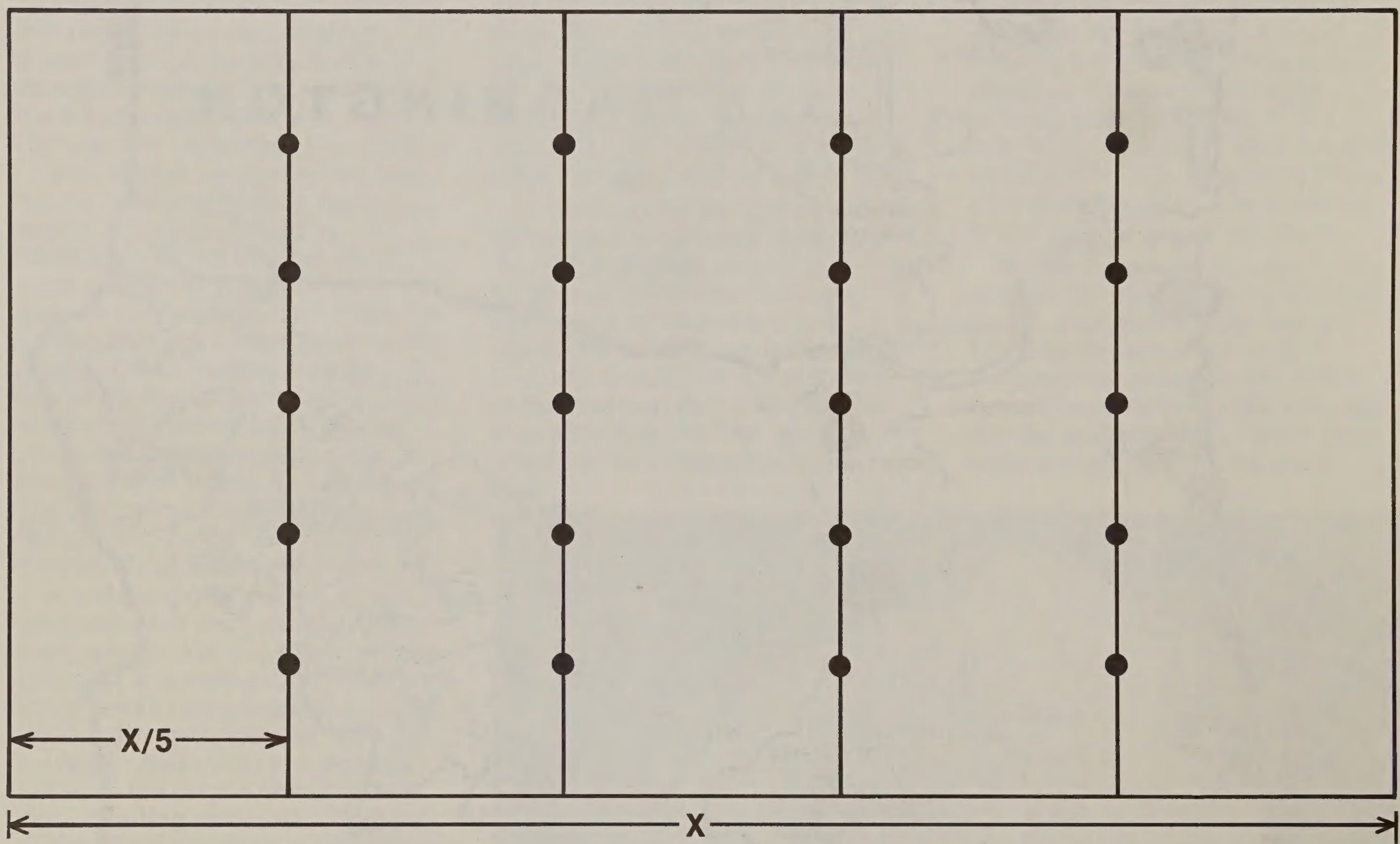

Figure 2. Sampling layout used in western hemlock decay evaluation: x = length of stand; $x/_5$ = distance between transects; plots are located 100 feet apart along transects.

volume defect in western hemlock (19) and, though it was measured, is not considered a component of loss in this evaluation. In the field, incipient decay and advanced decay were differentiated on the basis of visual appearance and ease of penetration by a knife point. Wood that could be penetrated by a sharp knife was classed as decayed.

If decay existed at the stump surface on felled sample trees, the trunk was dissected as high as the decay extended (Figures 4 and 5). The trunk was cut at 1 ft. intervals, decayed wood on the upper face of the bolt was outlined, with a felt-tipped pen, and the trunk section was numbered (Figure 6). The face of the section was then photographed (Figure 7) with an SX-70 Polaroid camera on a calibrated stand (28). In the

Figure 4. Dissecting the butt of a western hemlock, Bull Run, Oregon.

Figure 5. Western hemlock dissected at one foot intervals to the top of an extensive decay column, Aberdeen, Washington.

Figure 6. Outlining area of decay on the face of a disk from a decayed western hemlock, Aberdeen, Washington.

Figure 7. Photographing decay with Polaroid camera on calibrated stand, Bull Run, Oregon.

laboratory, area of decay on each photograph was measured using an electronic planimeter connected to a Hewlett-Packard model 9830A computer. Figures were expanded to represent actual size, and volume of decay in each tree was calculated by computer using Smalian's formula [volume = height x ((area of top + area of base)/2)].

Three disks were collected from each sample tree: one from the merchantable top, one from the stump top, and one from just above the root crown (ground level). These were returned to the laboratory, and growth measurements for the last 10 years were taken across four randomly-selected radii on each stump and merchantable top disk. Stump and ground level disks were surface sterilized in a 25% chlorox bath, rinsed in water, and split with a sterilized axe. Six chips were removed from any decayed or stained portions of each disk and plated on benomyl-malt agar. Disk sections were then wrapped in moist newspapers, incubated for 10 days to 3 weeks, and examined for evidence of fungi.

Fungi isolated from root samples, wound sections, or stem disks were identified or, if identification was impossible at our facilities, sent to the Forest Products Laboratory in Madison, Wisconsin for more intensive examination. *Fomes annosus* was identified on incubated wound sections, disks, and roots on the basis of formation of imperfect fruiting bodies *(Oedocephalum).*

Number and percentage of sample trees infected by all root and butt pathogens and by each individual pathogen or complex of pathogens were determined following identification of fungi on cultures, incubated roots, and disks. This percentage was assumed to approximate the amount of infection for all trees in the particular stand. Incidence of infection was compared in thinned and unthinned stands by Chi-square analysis and Fisher's exact test.

Cubic foot volume was calculated for each of the 320 sample trees using a modified Bruce's taper formula (Lampi personal communication):

$$\text{Tree volume ft}^3 = \text{log volume ft}^3$$
$$\text{Log volume ft}^3 = [((D(K)^2\ 0.00545) + (D(K+1)^2\ 0.00545))/2.0]\ XLN$$

Where $D(K)$ = small end diameter of the log
$D(K+1)$ = large end diameter of the log
XLN = log length

Sample tree volumes were plotted against DBH, and a regression equation was calculated as follows:

$$\text{Volume ft}^3 = -.5673 - .7133(DBH) + .31867(DBH^2)$$

$$R^2 = .878.$$

Using this equation, volumes of all trees tallied in basal area plots were determined, and per acre volume, trees per acre, and basal area tables were prepared for sample stands with the U.S. Forest Service, Region 6 VPLOT program (13).

Wood volume loss per acre due to butt and stem decay was determined by applying the percent volume loss measured in the sample trees to the total per acre volume. Losses for thinned and unthinned stands then were compared by analysis of variance.

Volume loss per acre due to decay in stems above the butt (higher than 6 feet) was estimated from data on size and age of stem wounds using the regression formula developed by Wright and Isaac (33):

$$Y_c = 0.0944 X_1 + 0.4910 X_2 - 0.0929$$

Where Y = decay volume in ft^3

X_1 = wound age in years

X_2 = wound area in ft^2

Actual measurements of decay volume associated with conks also were used. Percentage loss in sample trees again was applied to total volume per acre and the resulting estimates of stem losses were compared by analysis of variance for thinned and unthinned stands.

Measurements of 10-year leader and radial growth at the stump and the merchantable top were compared between (a) all apparently healthy trees and all infected trees and (b) trees in thinned and unthinned stands. Differences were tested by analysis of variance.

Results

Incidence of Infection by Decay-causing Fungi—Decay fungi were isolated from trees in all stands sampled. The pathogen most often isolated from sample trees was *F. annosus,* but *Armillaria mellea* (Vahl. ex Fr.) Quel. and *Haemato-stereum (Stereum) sanguino-lentum* (Alb. and Schw. ex Fr.) Pouz. also were common. Frequency of occurrence of these and other fungi encountered in the evaluation is shown in Tables 2 and 3.

Percentage of trees infected by root and butt decay fungi averaged 41.9 percent in thinned stands (range 30 to 50 percent), 23.1 percent in unthinned stands (range 5 to 40 percent), and 32.5 percent in both (Table 2). Thinned stands had a significantly ($P = .01$) greater incidence of infection. Wounding commonly was associated with infection. Eighty-eight percent of trees with butt wounds had associated infections. Fifty-seven percent of all trees with root and butt infections had butt wounds. The remaining 43 percent of the infected trees may have been infected via root contacts.

Since isolations were not attempted from all wounds on the stem above the butt, a precise measure of number of trees with stem infections was not obtained. However, in the subsample (10 percent) from which isolations were done, 86 percent of stem wounds had associated fungus infections.

Conks were found on only one sample tree. Two conks of *Phellinus (Fomes) pini* (Thore ex Fr.) Pil. were found on one 71-year-old tree in the Bull Run thinned stand. Eight percent of the cubic foot volume of that tree was found to be decayed.

Decay Losses—Wood volume losses due to decay are summarized in Table 4. Total volume losses were quite similar in thinned and unthinned stands. Decayed wood averaged 2.2 percent of the merchantable cubic foot volume in thinned stands (range 1.0 to

Table 1.—Historical information for stands examined in western hemlock decay evaluation.

Stand Location and Condition	Mean[a] Age (Years)	Thinning Date(s)	Other Disturbances
Forks Thinned	46.6	1967	...
Forks Unthinned	70.4	...	...
Seaside #1 Thinned	52.4	1968, 70, 72	...
Seaside #1 Unthinned	45.0	...	...
Seaside #2 Thinned	55.8	1968	...
Seaside #2 Unthinned	46.3	...	...
Aberdeen #1 Thinned	74.3	1966	...
Aberdeen #1 Unthinned	74.4	...	Old skid trail crossing edge
Aberdeen #2 Thinned	68.3	1953, 59	...
Aberdeen #2 Unthinned	82.6	...	Skid trail at edge of stand
Bull Run Thinned	70.8	1968	...
Bull Run Unthinned	76.2	...	Substantial bear damage
Verlot Thinned	102.8	1968	...
Verlot Unthinned	118.9	...	Two old roads or skid trails
Cathlamet Thinned	53.0	1968	...
Cathlamet Unthinned	55.1	...	Some old blow down & wounding

a/mean based on 20 trees per location

Table 3.—Fungi isolated from a subsample of wounds on the stems (above 6 foot height) of sampled western hemlock trees.

Fungus	Percent[a] of Wounds
Fomes annosus	29
Haematostereum sanguinolentum	7
Poria latemarginata	7
Unidentified Basidiomycetes	43
Any Basidiomycetes	86
No Basidiomycetes Isolated	14

a/ Percent based on isolations from 25 wounds on 23 trees.

Table 2.—Percentage of trees with roots and butts infected by decay fungi in western hemlock decay evaluation.

Stand Location and Condition	Percent[a] of Trees Infected by: *Fomes annosus*	*Armillaria mellea*	*Coriolus versicolor*	*Haematostereum sanguinolentum*	*Perenniporia subacida*	*Phlebia radiata*	*Poria latemarginata*	*Resinicium bicolor*	*Sistatrema* sp.	Unidentified Basidiomycetes	Any Basidiomycetes	No Basidiomycetes
Forks Thinned	25	25	0	0	0	0	0	5	0	15	45	55
Forks Unthinned	30	0	0	0	0	0	0	0	5	5	30	70
Seaside #1 Thinned	30	15	0	0	0	0	0	0	0	15	40	60
Seaside #1 Unthinned	5	5	0	0	0	0	0	0	0	5	15	85
Seaside #2 Thinned	25	10	0	5	0	0	0	0	0	10	40	60
Seaside #2 Unthinned	0	0	0	0	0	0	5	0	0	0	5	95
Aberdeen #1 Thinned	20	25	0	0	0	0	0	0	0	10	45	55
Aberdeen #1 Unthinned	5	20	0	0	0	0	0	0	0	5	25	75
Aberdeen #2 Thinned	30	10	0	0	5	0	0	0	0	10	50	50
Aberdeen #2 Unthinned	20	10	0	0	5	5	0	0	0	0	25	75
Verlot Thinned	20	5	0	5	0	0	0	0	0	10	30	70
Verlot Unthinned	5	0	5	0	0	0	0	0	0	5	15	85
Bull Run Thinned	25	0	0	5	0	0	0	0	0	10	35	65
Bull Run Unthinned	25	5	5	5	0	0	0	0	0	10	40	60
Cathlamet Thinned	35	0	5	10	0	0	0	0	0	0	50	50
Cathlamet Unthinned	15	5	0	5	0	0	0	0	0	10	30	70
Average All Thinned	26.2	11.2	0.6	3.1	0.6	0	0	0.6	0	10.0	41.9	58.1
Average All Unthinned	13.1	5.6	1.2	1.2	0.6	0.6	0.6	0	0.6	5.0	23.1	76.9

a/ Percents based on 20 trees per location. Rows of figures are not additive since some trees are infected by more than one fungus.

4.7 percent) and 3.3 percent in unthinned stands (range 1.2 to 6.8 percent). Translated to actual figures, this represents an average loss at rotation age of 194.5 cubic feet of wood per acre in thinned stands and 321.5 cubic feet per acre in unthinned stands. Thinned stands exhibited a significantly (P = 0.05) greater percentage of wood loss due to decay in butts, but unthinned stands showed a significantly (P = 0.05) greater amount of rot in the stems. Furthermore, amount of stem decay exceeded butt decay in both kinds of stands. Occurrence of decay was related strongly to past wounding. Eighty-seven percent of the volume lost to butt decay was associated with wounds while only 13 percent apparently resulted from spread of the fungus to the sample trees from infected roots alone. Comparison of amounts of butt decay in wounded and unwounded infected trees showed a significantly (P = 0.01) greater percentage of volume decayed in the wounded trees.

Among thinned stands, the Aberdeen #2 stand that was thinned 25 years before the evaluation exhibited about the same amount of decay as did the other stands that had all been thinned 10 to 12

Table 4.—Volume loss due to butt and stem decay in western hemlock decay evaluation.

Stand Location and Condition	Mean Western Hemlock Volume per Acre (ft^3)	Percent Volume with Butt Decay	Stem Decay	Total
Forks Thinned	4,218	1.4	1.1	2.5
Forks Unthinned	11,481	0.9	3.0	3.9
Seaside #1 Thinned	5,025	1.3	0.2	1.5
Seaside #1 Unthinned	6,443	0.0	2.6	2.6
Seaside #2 Thinned	6,767	0.3	2.5	2.8
Seaside #2 Unthinned	7,206	0.0	1.4	1.4
Aberdeen #1 Thinned	12,643	0.6	1.0	1.6
Aberdeen #1 Unthinned	12,776	0.1	1.1	1.2
Aberdeen #2 Thinned	12,928	0.5	1.5	2.0
Aberdeen #2 Unthinned	10,832	0.2	1.5	1.7
Bull Run Thinned	9,111	2.5	2.2	4.7
Bull Run Unthinned	7,809	2.4	3.2	5.6
Verlot Thinned	6,419	0.6	0.4	1.0
Verlot Unthinned	9,404	1.0	2.0	3.0
Cathlamet Thinned	13,617	0.4	1.2	1.6
Cathlamet Unthinned	11,884	0.1	6.7	6.8
Mean All Thinned	8,841	0.9	1.3	2.2
Mean All Unthinned	9,729	0.6	2.7	3.3
Mean All Stands	9,285	0.8	2.0	2.8

years before the evaluation (2.0 percent vs an average of 2.2 percent). Also, amounts of decay in stands that had been thinned more than once (Seaside #1 and Aberdeen #2) did not exceed amounts observed in stands that were entered only once (averages of 1.7 vs 2.4 percent).

Tables 5 and 6 summarize amount of decay attributed to each fungus species encountered in the survey. Based on isolation results, *F. annosus* was involved in almost 77 percent of the wood loss at the butt and 48 percent of the stem decay.

Mortality Losses—One sample tree (0.3 percent of trees sampled) was dead. This tree was located in an unthinned stand but had been injured severely 12 years before death. *Fomes annosus, Perenniporia subacida,* (Pk.) Donk and *Phlebia radiata* Fr. were isolated from the butt. Galleries of the hemlock engraver, *Scolytus tsugae* (Swaine), were found on the stem. Two other dead trees, one infected by *A. mellea* and infested by *S. tsugae* and the other infected by *Phellinus (Poria) weirii* (Murr.) Gilbertson, were observed in sampled stands but were not in sample plots. No windthrown western hemlock were encountered in the survey plots.

Growth Effects and Size Relationships—Mean size and 10-year growth data for apparently healthy, all decay fungi-infected, and *F. annosus*-infected trees are shown in Table 7. On the average, infected trees had greater heights and diameters. However, there were no statistically significant differences in radial and height growth for the last 10 years between infected and uninfected trees. Tree growth was good in all stands examined and in some cases was phenomenal. A tree at Forks, Washington had averaged almost one inch of diameter growth per year for its entire life, even though it was infected by *F. annosus.*

Trees in thinned stands exhibited a significantly (P = 0.05) greater amount of radial 10-year growth at stump height than did trees in unthinned stands. All other growth

Table 5.—Percentage of decay volume in the butt associated with each decay fungus or complex of decay fungi found in western hemlock evaluation.

Fungi	Percent of Decay[a]
Fomes annosus alone	50.6
Fomes annosus and Unidentified fungi	18.4
Fomes annosus and *Coriolus versicolor*	4.1
Armillaria mellea alone	2.7
Fomes annosus and *Armillaria mellea*	2.3
Haematostereum sanguinolentum alone	1.8
Armillaria mellea and *Resinicium bicolor*	1.4
Armillaria mellea and Unidentified fungi	1.0
Fomes annosus and *Haematostereum sanguinolentum*	0.7
Fomes annosus, Perenniporia subacida, Phelbia radiata	0.6
Coriolus versicolor alone	0.2
Perenniporia subacida alone	0.1
Poria latemarginata alone	0.1
Unidentified basidiomycetes	14.2
Any basidiomycete	98.2
No basidiomycetes isolated	1.8

a/ Percent based on 87 trees with 140.9 ft^3 of butt decay.

Table 6.—Percentage of decay in subsample of stem wounds associated with each decay fungus encountered in western hemlock decay evaluation.

Fungus	Percent of Decay[a]
Fomes annosus	48.3
Haematostereum sanguinolentum	8.8
Poria latemarginata	3.8
Unidentified basidiomycetes	33.0
Any basidiomycete	93.9
No basidiomycetes isolated	6.1

a/ Percent based on 25 wounds on 23 trees with an estimated 46.7 ft^3 of stem decay.

Table 7.—Size and growth parameters for apparently uninfected and infected western hemlocks examined in decay evaluation.

Condition	Number of Trees	Mean Total Height (ft.)	Mean DBH (in.)	Mean 10 Year Growth: Leader (ft.)	Stump (in.)	4" Top (in.)
Uninfected	217	90.7	18.9	12.26	2.24	2.84
Infected by any fungus	103	95.7	21.2	11.85	2.94	2.56
F. annosus Infected	64	95.3	21.6	11.67	2.62	2.52

measurement comparisons between thinned and unthinned stands showed no significant differences. Based on mean growth figures, annual increment for the last 10 years was about one and a third times greater in thinned than in unthinned stands. Mean annual increment for hemlock averaged 241.3 cubic feet per acre in all thinned and 188.9 cubic feet per acre in all unthinned stands for the last 10 years.

General Stand and Tree Character—Stand and tree characteristics for the 16 stands sampled in this evaluation are summarized in Tables 8, 9, and 10. Thinned stands tended to have the expected fewer trees per acre of larger size and more uniform crown class than did unthinned stands. Dwarf mistletoe infection intensity was about the same in thinned and unthinned stands (Table 10).

Tree Wounding—Wounds were common in most stands (Figure 8). In addition to logging equipment and falling trees, feeding by black bears, *Ursus americanus* and mountain beavers, *Aplodontia rufa*, resulted in a large number of wounds. There were substantially more butt wounds in thinned than in unthinned stands (Table 11). However, trees in unthinned stands had more wounds above the butt (over 6 feet high on the stem). In addition, stem wounds in unthinned stands were larger and older than those in thinned stands (mean size of 99.9 vs 52.3 in^2 and mean age of 16.4 vs 14.7 years, respectively).

Figure 8. Severe wounding in a thinned western hemlock stand, Bull Run, Oregon.

Table 8.—Mean number of trees, square foot basal area, and cubic foot volume per acre for surveyed western hemlock stands.

Stand Location and Condition	Trees Per Acre: Western Hemlock	Trees Per Acre: Other Species	Trees Per Acre: Total	Trees Per Acre: Standard Error	Basal Area Per Acre: Western Hemlock	Basal Area Per Acre: Other Species	Basal Area Per Acre: Total	Basal Area Per Acre: Standard Error	Cubic Foot Volume Per Acre (M): Western Hemlock	Cubic Foot Volume Per Acre (M): Other Species	Cubic Foot Volume Per Acre (M): Total	Cubic Foot Volume Per Acre (M): Standard Error
Forks Thinned	74.3	42.4	116.7	24.1	84	80	164	10.7	4.218	4.118	8.336	.491
Forks Unthinned	312.8	80.9	393.7	60.5	242	45	287	16.4	11.481	2.078	13.559	.760
Seaside #1 Thinned	91.7	23.0	114.7	13.9	103	42	145	9.0	5.025	2.169	7.194	.444
Seaside #1 Unthinned	132.0	128.5	260.5	28.7	134	124	258	18.2	6.443	6.108	12.551	.847
Seaside #2 Thinned	100.3	10.7	111.0	23.0	132	27	159	14.0	6.767	1.411	8.178	.702
Seaside #2 Unthinned	148.9	151.7	300.6	21.3	148	170	318	15.2	7.206	8.385	15.591	.773
Aberdeen #1 Thinned	214.8	15.9	230.7	94.9	248	16	264	21.4	12.643	0.811	13.454	1.101
Aberdeen #1 Unthinned	143.2	25.4	168.6	18.4	252	20	272	15.2	12.776	1.010	13.786	.774
Aberdeen #2 Thinned	193.2	12.4	205.6	37.2	258	26	284	20.3	12.928	1.404	14.332	.990
Aberdeen #2 Unthinned	180.6	1.9	182.5	94.5	210	4	214	21.2	10.832	0.214	11.046	1.099
Bull Run Thinned	164.6	22.2	186.8	26.8	188	40	228	16.9	9.111	2.007	11.118	.800
Bull Run Unthinned	137.4	44.8	182.2	17.5	159	76	235	15.3	7.809	3.853	11.662	.750
Verlot Thinned	66.6	22.1	88.7	10.8	125	61	186	15.2	6.419	3.248	9.667	.782
Verlot Unthinned	77.1	29.1	106.2	15.2	178	76	254	18.9	9.404	4.000	13.404	.998
Cathlamet Thinned	151.0	3.1	154.1	10.3	270	10	280	17.4	13.617	0.534	14.151	.885
Cathlamet Unthinned	214.3	3.2	217.5	40.2	240	12	252	20.5	11.884	0.632	12.516	.991
Mean All Thinned	132.1	19.0	151.1		176	38	214		8.841	1.963	10.804	
Mean All Unthinned	168.3	58.2	226.5		195	66	261		9.729	3.285	13.014	

Table 9.—Mean[a] size and growth parameters for trees in stands examined in western hemlock decay evaluation.

Stand Location and Condition	Mean DBH (in.)	Mean Total Height (ft.)	Mean Merchantable Height (ft.)	Mean Stump Dib. (in.)	Mean 40 ft. Dib. (in.)	Mean 10 yr. Growth Leader (ft.)	Stump (in.)	4" Top (in.)
Forks Thinned	18.0	106.3	86.4	20.5	12.7	18.5	3.0	3.6
Forks Unthinned	17.2	100.3	81.8	18.0	10.4	11.2	1.4	2.6
Seaside #1 Thinned	18.3	98.8	79.5	18.7	12.2	13.2	3.8	2.8
Seaside #1 Unthinned	14.0	90.2	71.6	14.8	9.5	15.7	2.4	3.4
Seaside #2 Thinned	20.1	110.6	91.5	21.0	13.9	14.3	3.4	3.0
Seaside #2 Unthinned	15.0	95.1	77.2	15.3	10.5	14.7	1.8	3.4
Aberdeen #1 Thinned	19.2	128.4	110.9	22.8	14.3	11.1	2.2	2.0
Aberdeen #1 Unthinned	19.5	133.1	114.0	22.7	14.9	13.8	1.6	2.6
Aberdeen #2 Thinned	18.7	119.4	101.8	21.4	13.6	10.4	2.6	2.4
Aberdeen #2 Unthinned	20.2	130.6	112.3	22.9	15.0	8.6	1.4	2.0
Bull Run Thinned	15.1	106.1	89.1	16.8	11.3	7.2	2.2	1.8
Bull Run Unthinned	16.1	118.3	99.1	18.4	12.2	10.9	1.8	2.4
Verlot Thinned	20.2	127.2	111.3	21.8	15.0	5.8	2.0	1.4
Verlot Unthinned	19.0	105.8	89.5	20.4	13.3	8.5	1.8	1.8
Cathlamet Thinned	17.5	109.3	91.7	19.5	13.4	15.0	3.2	3.2
Cathlamet Unthinned	16.4	96.2	78.7	19.1	11.2	13.6	2.2	3.4
Mean All Thinned	18.4	113.3	95.3	20.3	13.3	11.9	2.8	2.5
Mean All Unthinned	17.2	108.7	90.5	18.9	12.1	12.1	1.8	2.7

a/ Means based on 20 samples per stand.

Discussion

Our data show that wood loss due to decay is very small in 40- to 120-year-old western hemlock stands relative to that reported in old-growth hemlock: a mean of 2.8 percent of the merchantable cubic foot volume in young-growth as opposed to 25 to 52 percent in the old-growth (3,11). This is true even though young western hemlock stands, especially those that have been thinned, exhibit high levels of infection by decay fungi. Apparently, development of advanced decay in western hemlock is a slow process, requiring many years. Englerth (8) indicated that in his studies most substantial amounts of decay were observed in trees 180 years old or older.

Much of the decay that does develop in young western hemlocks is associated with wounds. Many researchers (15, 20, 23, 24, 26, 31) indicate that the close association between decay and wounding is due to the fact that wounds serve as the major infection courts for the fungi that cause decay. It is also possible that wounding activates decay fungi already in the wood in a fashion similar to that outlined by Etheridge and Craig for Indian paint fungus (10).

Amount of decay is quite similar in young stands that have been thinned commercially and those that have not had management entrances. However, amount of decay is greater in the butts of trees in thinned than unthinned stands and greater in the stems of

Table 10.—Crown class and dwarf mistletoe rating data for stands examined in western hemlock decay evaluation.

Stand Location and Condition	Percent of Trees in Crown Class: Suppressed	Intermediate	Codominant	Dominant	Percent of Trees in Dwarf Mistletoe Rating Class: 0	1	2	3	4	5	6
Forks Thinned	0	5	90	5	80	10	5	0	5	0	0
Forks Unthinned	5	20	75	0	75	5	10	0	5	0	5
Seaside #1 Thinned	5	20	75	0	100	0	0	0	0	0	0
Seaside #1 Unthinned	0	35	65	0	100	0	0	0	0	0	0
Seaside #2 Thinned	0	5	95	5	100	0	0	0	0	0	0
Seaside #2 Unthinned	0	25	75	0	100	0	0	0	0	0	0
Aberdeen #1 Thinned	0	15	85	0	60	5	5	15	15	0	0
Aberdeen #1 Unthinned	0	20	80	0	70	5	10	5	5	5	0
Aberdeen #2 Thinned	15	10	65	10	25	10	25	10	20	10	0
Aberdeen #2 Unthinned	0	30	65	5	30	0	10	10	5	20	25
Verlot Thinned	0	25	55	20	90	5	5	0	0	0	0
Verlot Unthinned	5	40	50	5	95	0	0	0	5	0	0
Bull Run Thinned	0	35	60	5	50	25	15	5	0	0	5
Bull Run Unthinned	5	20	75	0	40	15	10	10	10	10	5
Cathlamet Thinned	0	0	90	10	90	10	0	0	0	0	0
Cathlamet Unthinned	5	5	80	10	70	20	10	0	0	0	0
Mean All Thinned	2	14	77	7	74	8	7	4	5	1	1
Mean All Unthinned	2	24	71	3	73	6	6	3	4	4	4

trees in unthinned than thinned stands. Possible reasons for the greater amount of butt decay in thinned stands are (a) increased amounts of root to root spread of *F. annosus* to crop trees from adjacent stumps created during thinning and/or (b) infection by or activation of decay fungi in the larger number of butt wounds caused by logging equipment and skidded trees in thinned stands. The facts that (a) incidence of decay is greater in wounded than unwounded trees and (b) that volumes of butt decay associated with wounds are significantly greater than volumes of butt decay found in unwounded trees suggests that the latter reason is more important. Occurrence of greater amounts of decay in the stems of trees in unthinned than thinned stands is due to the larger number of stem wounds (and stem wounds of greater size and age) in such stands. This is probably the result of (a) close spacing of trees in such stands resulting in a greater number of injuries due to contacts between trees and (b) selective removal of previously injured trees in the commercially thinned stands.

Concern has been expressed that thinnings in young hemlock stands will increase the volume of infected roots in the soil. Speculation is that this increase in inoculum might cause damage from root and butt decay to increase with each rotation. Our data suggest that an increase in inoculum does occur with thinning but that the associated increase in damage is small. With the possible exception of the stands at Verlot, all stands that we sampled had developed on hemlock sites that had been clearcut. Many of the hemlock stumps created by the clearcutting operations of 40 to 120 years ago undoubtedly became infected by *F. annosus*. Yet volume lost to decay fungi in the present stands was relatively small even though in all likelihood there were substantial quantities of inoculum in the soil. We suggest that exposure to large quantities of inoculum alone will not necessarily result in large decay losses. But, we believe exposure to large quantities of inoculum combined with tree wounding and long rotations will.

Death of western hemlock infected by decay fungi is rare in stands of the ages examined in this investigation. *Fomes annosus,* though common in young western hemlock, acts very differently in this species, where it mainly causes decay of internal woody tissues, than it does in such resinous conifer hosts as pines, where it attacks the cambium and commonly kills the tree.

Based on our analysis, infection by decay fungi does not affect growth of young western hemlock to an appreciable degree. Chavez (personal communication) also found no differences in growth between young, *F. annosus*-infected and uninfected western hemlock in northwestern Washington. Mean heights and diameters of infected trees examined in our evaluation were greater than those of uninfected trees in spite of the fact that growth for the last 10 years was quite similar in both groups. This may indicate that larger trees have a greater probability of being wounded and infected or that large trees have a greater likelihood of being infected via root contacts because of their wider spreading root systems.

Table 11.—Location of wounds, percent of trees with wounds, and number of wounds per injured tree found in western hemlock decay evaluation.

Stand Location and Condition	Percent[a] of Trees with Wounds			No. of Wounds per Injured Tree		
	Butt[b]	Stem	Any	Butt[b]	Stem	Any
Forks Thinned	20	20	35	1.2	1.5	1.6
Forks Unthinned	5	15	20	1.0	1.3	1.2
Seaside #1 Thinned	35	15	45	1.1	2.3	1.7
Seaside #1 Unthinned	0	30	30	...	1.7	1.7
Seaside #2 Thinned	20	25	35	1.2	1.8	2.0
Seaside #2 Unthinned	0	40	40	...	2.5	2.5
Aberdeen #1 Thinned	25	40	55	1.6	1.5	1.8
Aberdeen #1 Unthinned	15	25	30	1.0	1.4	1.5
Aberdeen #2 Thinned	20	15	30	1.0	1.7	1.5
Aberdeen #2 Unthinned	10	25	35	1.0	2.0	1.7
Bull Run Thinned	35	30	60	1.9	2.2	2.2
Bull Run Unthinned	50	25	65	1.6	1.8	1.9
Verlot Thinned	20	25	35	1.2	1.8	2.0
Verlot Unthinned	15	15	25	1.3	1.0	1.4
Cathlamet Thinned	40	30	55	1.2	1.8	1.9
Cathlamet Unthinned	10	55	55	1.0	4.4	4.5
Mean All Thinned	26.9	25.0	43.7	1.3	1.8	1.8
Mean All Unthinned	13.1	28.7	37.5	1.1	2.0	2.0

a/ Percents based on 20 trees per location.

b/ Lower six feet of stem.

Management Implications

Based on our results, we suggest the following recommendations for foresters managing western hemlock:

(1) **Manage on Short Rotations**—Preferably about the age range of stands examined in our survey (40 to 120 years).

(2) **Minimize Wounding**—Concentrate on avoiding any tree injury, especially when thinning. Incorporate wound prevention guidelines into timber sale contracts. Discriminate against already wounded trees during thinning operations.

(3) **Do Not Avoid or Delay Thinning Because of Perceived Potential Decay Losses**—We found very little difference in amount of decay in commercially thinned and unthinned western hemlock stands. Furthermore, our data show that growth increases resulting from commercial thinning greatly outweigh decay losses. High quality logging operations that result in few trees being wounded will cause little, if any, actual decay to develop in thinned stands. Precommercial thinning's effect on decay was not evaluated in this investigation since it was not possible to locate rotation age stands that had been precommercially thinned. Chavez (personal communication) examined two plots in 26-year-old stands that had been precommercially thinned at age 15. High percentages of trees were infected by *F. annosus* and some had substantial amounts of stain, but amounts of actual decay were small. Decay in precommercially thinned stands needs to be examined in more detail as such stands reach rotation age. However, we believe that the benefits of precommercial thinning will exceed loss caused by decay. Tree wounding which plays a major role in decay development is not so common in precommercial as it is in commercial thinning. Decay that develops as a result of precommercial thinning wounds tends to be compartmentalized (i.e., occupies a small cylinder representing the stem size at time of wounding), and stumps created during precommercial thinning operations are small and not as efficient disease carriers as larger stumps.

(4) **Stump Treatment is Usually Unnecessary**—Infection of freshly-cut hemlock stumps by *F. annosus* can be prevented by treating the surface with one of several chemicals, usually sodium borax (21). These treatments are effective in preventing new infections, but they only work if the stumps are not already infected. They also are rather time-consuming and hence expensive. Based on the relatively small amounts of decay found in our survey, the high incidence of infection already occurring in both managed and unmanaged stands and the fact that much more decay was associated with wounds than with stump infections, we hesitate to recommend stump treatment as an effective, economically justifiable control technique in commercial western hemlock stands. Such treatments may be worth using in areas with high value trees, such as recreation sites and seed tree orchards, if it can be established that there is little or no prior infection.

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