Heterobasidion (Fomes) Annosum Incidence in Pre-Commercially Thinned Coastal Washington Western Hemlock Stands[1]

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Abstract: Heterobasidion annosum infects western hemlock (Tsuga heterophylla) and causes a root and butt-rot disease. A disease survey was initiated in thinned Southwestern Washington hemlock stands to determine current disease incidence caused by H. annosum.

Eleven stands were selected which had been pre-commercially thinned in the interval 5-11 years ago. Ten replicate 1/50th acre plots were established per stand and' all hemlock trees were cored with increment borers. Core samples were cultured to isolate decay fungi and to determine decay incidence and the occurrence of "wetwood".

Levels of infection by H. annosum in pre-commercially thinned western hemlock stands were low (0-8 percent). Merchantable volume loss from decay ranged from 0-1 precent [sic]. Infection levels were not correlated with site characterisitics, [sic] "wetwood" incidence, cutstump frequency or tree diameter class. No control measures appear warranted for thinnings in hemlock stands where similar low infection potentials exist.

Heterobasidion annosum (Fr.) Bref. infects western hemlock (Tsuga heterophylla (Rfn.) Sarg.) and causes a root and butt-rot disease (Russell and others 1973, Driver and Edmonds 1970). Nearly two decades ago, it was recognized that thinning initiated root disease could be a potentially limiting factor in intensive hemlock management (Morrison and Johnson 1970, Wallis and Reynolds 1970, Driver and Edmonds 1970). Epidemiological and disease incidence studies were initiated because of concern over this disease potential (Edmonds and others 1989).

Disease incidence surveys conducted in non-thinned hemlock stands in Washington and Oregon indicate that infection levels ranged from 10 to 67 percent (Schmidt 1979). Likewise, Goheen and others (1980) reported lower levels of infection (0-30 percent) for a similar hemlock stand series. At two non-thinned Washington sites (Raymond and Snoqualmie), we determined that 0-15 percent of the residual western hemlock trees were infected.[3]

More dramatic disease increases have been reported following hemlock thinning. Chavez and others (1980) reported significant disease increases at Clallam Bay, Washington, over infection levels reported a decade earlier by Edmonds (1968). Ten years after thinning, Chavez determined that some 85 to 95 percent of the residual stand was infected, in contrast to prethinning infection levels of 4 to 12 percent (Edmonds 1968).

Edmonds and others (1989) report that current (pct+20 years) infection levels on the same study site of Chavez (1980) fail to confirm that a disease increase occurred. This apparent conflict in disease incidence observations following thinning has not been fully explained (Edmonds and others 1989). We feel that variation in wood incubation techniques and the mistaken identity of "wetwood" as incipient H. annosum root decay may have led to conclusions by Chavez and others (1980) that a disease increase had occurred, when in fact it had not. To better understand current annosus root disease levels and its impact, a disease survey was initiated in thinned coastal western hemlock stands in Washington.

Our hypothesis was: hemlock stands thinned from high initial stocking densities (>3000 trees per acre [TPA]) and older age classes >20 years) have a higher incidence of annosus root disease, than younger stands thinned from lower initial stocking densities.

The specific study objectives were:
(1) identify site and stand characteristics associated with high disease incidence
(2) determine current infection levels by H. annosum in thinned hemlock stands and
(3) determine current disease impact.

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[3] Unpublished data on file at Centralia Research Center Library, Centralia , Washington.

METHODS €

Site Descriptions€

Sample sites were located in southwest € Washington in Pacific, Grays Harbor, and Lewis € counties. Figure 1 shows the study site loca-€ tions, relative to Aberdeen, Washington. Stands € were identified by name of nearest major road € system (name-line) or by nearest access road num-€ ber. The study included portions of the Falls € Creek C-Line, Lund A-line, Nemah X&Y-Lines, Palix € A&D-Lines, and Trap Creek D-line (Figure 1). €

Hemlock soil site index values were 100 or € 110 feet at breast height age 50 years € (Steinbrenner and Duncan 1969). This index refers € to average height growth of western hemlock on a € site at stand age 50 years. The soils are of € volcanic origin and are classified in the Bunker, € Katula, Knappton, or Vesta series (Table 1). € Stand elevation varied from 500 to 2500 feet, € and slopes ranged between 17 and 53 precent [sic]. €

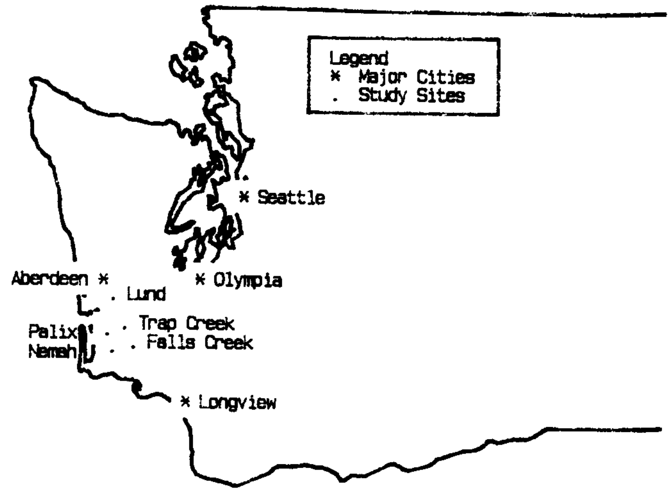

Figure 1--Locations of western hemlock stands € sampled for infection by Heterobasidion annosum€ in Washington State €

Table 1--Site characteristics of western hemlock stands in Washington State € surveyed for Heterobasidion annosum incidence €

Stand name	Soil site index[1]€	Soil series[2]	Elevation	Slope	€
			feet	percent	
Falls Creek C2600[3]	100	Bunker	2500	35	
Falls Creek C6700	100	Bunker	2500	25	
Falls Creek C6790	100	Bunker	2500	17	
Lund A800	100	Bunker	500	24	
Nemah X130	110	Knappton-Vesta	550	53	
Nemah Y1710	110	Knappton	550	19	
Palix A2100	110	Knappton-Vesta	600	31	
Palix A2710	110	Knappton-Vesta	600	28	
Palix D2000	100	Vesta	2200	23	
Palix D2300	110	Knappton-Vesta	2200	26	
Trap Creek D920	100	Katula	1750	47	

[1]€ Soil site index - height in feet at breast height age 50 € years (Steinbrenner and Duncan 1969). €

[2] Soil series classification (Steinbrenner and Duncan 1969). €

[3] Major access line and road number respectively. €

TPA pre-thin density	Stand Age at Thinning (Yrs) 15-20	>20
<3000	Lund A800[1] Palix A2100 Palix A2710	Falls Creek C2600 Falls Creek C5700 Nemah X130 Nemah X1710 Trap Creek D920
>3000	NS*	Falls Creek 6790 Palix D2000 Palix D2300 Bishop A450

* NS - no samples present

[1] Stand name designated by service road (name) and access road number (letter and number)

Figure 2--Relative position of survey stands to sampling matrix constructed using plot measurement data for pre-thin stand age density and stand age.

Plot Design and Measurements

Survey transects at 5-chain intervals were overlaid on stand maps. Ten circular 1/50th acre plots per stand were established at randomly selected points from this overlay. Tree diameters were measured for plot trees larger than 4.5 inches in diameter at breast height (dbh). Cut-stumps from previous thinning activities and all other similar-aged tree stumps within a 3-foot radius of each plot tree were tallied. Pre-thinning and current stocking levels were calculated for each stand by using plot residuals and cutstump tallies. This plot data filled a sampling matrix of stocking density by stand age combinations. Figure 2 shows the sample matrix breakdown by density and age.

Hemlocks on each plot were cored at stump height (6 inches) with an increment borer. Cores were extracted through the bole to the stem pith region and perpendicular to an imaginary line through the stem to the nearest cutstump. This was determined by experience to give the greatest probability of intersecting a decay column, if present. Extracted cores were stored at the end of each day in a cold room at 33°F, and plated within 2-3 days.

Disease Status

Tree disease status was visually determined from the cores and later confirmed by fungal isolations as: (1) infected with _H. annosum_, (2) containing other decay fungi, or (3) having "wetwood" stain with or without other decay fungi.

Fungal Isolations

Cores were dipped in 70 percent ethanol and flame sterilized prior to fungal isolation. Cores partitioned into 2-inch long pieces were plated onto media selective for _H. annosum_ (Kuhlman and Hendrix 1962). Plates were incubated 3 weeks at 25°C and examined for the _Oedocephalum_.

Sporophore Occurrence

Fruiting bodies of _H. annosum_ were collected from survey plots and their age was estimated by counting successive hymenial surface layers. More than one hymenial layer can be formed in a year, but a maximum potential age for the individual sporophores can be calculated in this manner.

Analysis

Study results were tested for significant differences (p = .05) between stand infection levels and various stand and site parameters by using ANOVA PC/SAS Version 6 (SAS Institute Inc. 1987).

RESULTS/DISCUSSION

Stand Characteristics

Western hemlock was the predominate component (97 percent) in our study (Table 2), with minor components of Douglas-fir (_Pseudotsuga menziesii_ Mirb. Franco.), silver-fir (_Abies amabilis_ Dougl. Forb.), and Sitka spruce (_Picea sitchensis_ Bong. Can.) present in some stands. Our study concentrated on hemlock stands currently 26-39 years old (Table 2). Stand age was expressed as the time since the previous harvest, and not actual tree age. We found that tree age and stand age could differ by as much as 15 years, because some trees could be nonmerchantable carry-overs from the previous stand.

All stands had been regenerated naturally following harvest. The Falls Creek sites were slash-burned, and the remaining sites were not (Table 2). Site preparation affected the occurrence of hemlock dwarf mistletoe (_Arceuthobium_ tsugense (Rosendahl) G.N. Jones). This disease was common in nonburned stands,, but absent in slash-burned units.

Stand density at thinning was calculated to range from 1485 to 4205 trees per acre (TPA) (Table 2). These stands were subsequently precommercially thinned with chainsaws between 5 and 11 years ago. Cut-stumps were not treated with borax. Post-thinning stocking levels varied from 260 TPA to 570 TPA.

Table 2--Stand description of site preparation, western hemlock composition, current stand age, holding time since pre-commercial thinning (PCT), pre-thin stocking density (TPA), and current stocking levels. Data based on ten 1/50th-acre plots per stand

	Site	Hemlock	Current[1]	Years Since	Stand density[3]	
Stand name[1]	prep	composition	stand age	Thinning	Pre-thin	Current
		Percent	Years		TPA	TPA
Falls Creek C2600	Burned	91	36	8	2380	335
Falls Creek C6700	Burned	99	36	6	1880	385
Falls Creek C6790	Burned	99	36	6	3000	350
Lund A800	None	96	26	8	1485	260
Nemah X130	None	100	29	5	2260	315
Nemah Y1710	None	100	29	5	2790	345
Palix A2100	None	99	30	11	2855	360
Palix A2710	None	86	30	11	2015	270
Palix D2000	None	100	31	10	4205	570
Palix D2300	None	100	30	9	3620	340
Trap Creek D920	None	95	32	6	2115	305

[1] The letter and number designations that follow the stand names identify the road line (letter) and secondary access road number.

[2] Years since last harvest and not actual tree age.

[3] TPA - stand density in trees per acre.

Disease Survey Data

The survey data were used to determine disease incidence, decay levels, and to identify factors related to infection levels. Disease status was based on examination of cultures from 769 hemlock tree cores. We distinguished between incipient and advanced decay caused by *H. annosum* and "wetwood." The occurrence of sporophores of *H. annosum* and cutstump frequency were measured as disease factors.

Levels of Infection by Heterobasidion annosum

Levels of infection caused by *H. annosum* in precommercial thinned western hemlock stands throughout this study were low; they ranged from 0 to 8 percent (Table 3). The Lund A800 site had the highest infection level. Infection levels of 0 to 2.9 percent were observed in the Falls Creek stands. At Trap Creek D920 3.4 percent of the trees were infected with *H. annosum*. The fungus was not isolated from plots of the Palix A2100, Falls Creek C2600, A2710, D2300 or Nemah Y1710 stands.

Our results indicate that infection levels of *H. annosum* in pre-commercially thinned western hemlock stands are much lower than previously reported. Schmidt (1978) observed that stand elevation and geographic location had an effect on stand infection levels. He found higher levels (40-50 percent) in Pacific County (Washington), and slightly lower levels (30-50 percent) in Washington Cascade stands. In similar locations, Coheen and others (1980) reported disease levels to be from 5-20 percent and 20-30 percent for non-thinned and thinned stands, respectively. Chavez and others (1980) reported that 85 to 95 percent of hemlock residuals in a Clallam Bay, Washington, thinned stand were infected. New unpublished data obtained by the authors and others (Edmonds and others 1989) do not support these earlier study results. In contrast, we suggest that infection levels in the range of 0 to 15 percent may be typical for thinned or nonthinned western hemlock stands under 50 years of age.

In our case, the post-thinning holding time period (5 to 11 years) should have been long enough to allow for sufficient pathogen movement from cutstumps to residual trees based on published fungal growth rates -- 0.75m/year (Wallis and Morrison 1975, Chavez and others 1980). We did not see a trend in our data for more disease with longer holding period. Other studies sampled stands following similar post-thinning periods. For example, Goheen and others (1980) sampled stands 12-21 years after thinning, while Chavez and others (1980) reported on a 10-year post-thinning holding period.

The distribution of hemlock trees infected by H. annosum by diameter class has not been previously reported in the literature. Table 4 illustrates that infected trees occurred throughout the diameter distribution of our study sites.

Decay In Trees

Decay frequency, including that caused by H. annosum, is shown in Table 3. H. annosum was the most frequent pathogenic root decay fungus isolated. Earlier studies have shown H. annosum to be a major component of decay in western hemlock (Shea 1960, Goheen and others 1980, Wallis and Morrison 1975).

Advanced bole decay was observed in residual hemlocks in all stands except Nemah Y1710. Decay may also result from other fungal species. Armillaria sp. (ostoyae) was isolated from decayed cores of two trees. Perenniporia subacida and other fungal species were isolated infrequently. Fungi Imperfecti and bacteria associated with decay were isolated but these were not identified.

Decay impact on a stand level was minimal owing to the low infection levels. Merchantable losses from decay were estimated to be less than 1 percent of stand volume. This is less than the 2 to 3 percent merchantable volume loss measured by Goheen and others (1980). Decay development over the remaining portion of the rotation (20 years or so) will add additional impact, as the column of decay continues to develop.

Wetwood Stain

Dark-stained, water-soaked core wood in western hemlock has been termed "wetwood" (Schroeder and Kozlik 1972). This type of wood has been associated with warping, annual ring separation (shake), and drying problems in western hemlock.

In our study, 45 percent of sampled trees contained "wetwood" stain at the stump level (Table 3). "Wetwood" was most prominent in the Palix D2000 unit, and it was least common in an adjacent stand, Palix D2300 (57 percent versus 31 percent, respectively).

"Wetwood" is believed to arise from branch origin, but may also be a by-product of wood-decaying microorganisms (Edmonds and others 1989). Because of its appearance, "wetwood" has been

Table 3--Summary of disease data from sampled stands of western hemlock showing percentages of infection by Heterobasidion annosum, percent trees with bole decay, and "wetwood" occurrence. Data based on averages from ten replicate 1/50th-acre plots per stand

Stand name[1]	H. annosum infection[2]	Decay trees[3]	"Wetwood"
	Percent	Percent	Percent
Falls Creek C2600	0 a[4]	3.8 ab	49 abcd
Falls Creek C6700	1.3 a	1.3 ab	45 abcd
Falls Creek C6790	2.9 ab	4.4 ab	31 cd
Lund A800	8.0 b	8.0 a	46 abcd
Nemah X130	4.8 ab	6.0 ab	54 abc
Nemah Y1710	0.0 a	0.0 b	48 abcd
Palix A2100	0.0 a	1.4 ab	37 bcd
Palix A2710	0.0 a	0.1 ab	47 abcd
Palix D2000	0.9 a	0.9 ab	57 ab
Palix D2300	0.0 a	4.4 ab	31 cd
Trap Creek D920	3.4 ab	6.9 ab	53 abc

[1] The letter and number designations that follow the stand names identify the road line (letter) and secondary access road number.

[2] Percent age of trees with H. annosum.

[3] Percent trees with incipient or advanced decay including those with H. annosum.

[4] Means followed by different letters are significantly different at P = 0.05 as determined by Duncan's New Multiple Range T-test.

mistakenly identified as a symptom caused by H. annosum in infected wood. Our isolations confirm that "wet-wood" is a poor indicator of incipient infection by H. annosum. Bacteria and various Fungi Imperfecti (Trichoderma sp., etc.) were consistently isolated from "wetwood."

Disease Factors

Sporophore Occurrence

Fruiting bodies (sporophores) are the source of airborne inoculum of H. annosum that infects freshly cut stumps and wounded trees. The presence of sporophores has important bearing on stand infection levels, because sporophores confirm that the fungus is present and producing spores which could contribute to more infections. We frequently observed active sporophores on stumps and logging slash from the previous stand, and less frequently on thinning-aged slash. The quantity of sporophores present on a area sampling basis differed between stands (Table 5). Sporophores could not be found in the slash burned stands at the Falls Creek sites (C6700, C2600, and C6790). Slash burning might inhibit or delay fruiting through decreased initial infection rates, consuming substrates where fruiting might occur, or by changing the fruiting microenvironment. The interactions between fire and H. annosum have been poorly studied (Russell and others 1989).

Other factors (such as elevation) could affect sporophore production. The Falls Creek sites, where no fruiting of H. annosum was observed, were at the highest elevation (2500 feet) sampled. Infection rates and fungal growth might be adversely affected at higher elevations, further contributing to delayed fruiting.

Table 4--Distribution of H. annosum infected trees and the percent of trees infected in each 1 inch DBH diameter class.

DBH Diameter class	No. trees	No. infected trees	Percent infection
4.5 - 5.0	16	0	0
5.5 - 6.0	30	3	10
6.5 -7.0	64	1	1.6
7.5 - 8.0	116	2	1.7
8.5 - 9.0	133	4	3
9.5 - 10.0	117	2	1.7
10.5 - 11.0	110	2	1.8
11.5 - 12.0	73	0	0
12.5 - 13.0	47	1	2.1
13.5 - 14.0	34	0	0
14.5 - 15.0	18	0	0
15.5 - 16.0	9	0	0
16.5 - 17.0	4	0	0
17.5 - 18.0	1	0	0
18.5 - 19.0	1	0	0
19.5 - 20.0	1	0	0

In contrast to the Falls Creek site, non-burned stands had varying populations of active sporocarps. Sporophores were observed on 20 percent of the plots in four stands (Trap Creek. D920, Palix D2300, D2000; and Lund A800), while higher sporophore concentrations (40 percent of the sample area) occurred in the Nemah X130 and Palix A2710 units. The greatest numbers of sporophores were observed in the Nemah Y1710 unit where 90 percent of the plots had active sporophores. The availability of suitable woody substrates (stumps and logs) appeared related to fruiting abundance, but this was not quantified in this study.

Sporophore age ranged from 3 to 6 years old in most units, with occasional older "conks" being from 11 to 16 years old. These data indicated that peak sporophore occurrence did not coincide with stand thinning date. Thinning was done when relatively few active sporophores were present in these stands. This could explain the low correlation between current sporophore density and stand infection levels.

Previous researchers reported high levels of stump infection, but gave no clue as to inoculum source (Driver and Edmonds 1970). We suggest that in our study, stands were thinned when low background levels of inoculum were present. The source of this inoculum could be from the relatively few sporophores present in the stand and from sources outside the stand.Risk of tree infection within a stand could be augmented if greater sporophore density coincided with thinning, since spore sources and suitable fresh cut-stumps would be in close proximity.

Other fungi might successfully compete with H. annosum for available substrates, resulting in low infection rates. We observed numerous sporophores of Perenniporia subacida, Ganoderma oregonensis, Neamatoloma capnoides, Pholiota sp., and Fomitopsis pinicola on stumps and logging debris, and on thinning slash. The beneficial role that these competing fungi may play in disease reduction in hemlock stands has not been quantified.

Cutstump Distribution

Cutstumps are a primary infection court for H. annosum, although wounds and animal damage also provide infection counts (Chavez and others 1980). Our initial hypothesis stated that stands thinned from a higher stand stocking density would develop higher levels of disease than those thinned from lower initial stand stocking densities. This hypothesis assumed that greater cutstump frequencies around individual trees would create greater infection potential.

The average cutstump frequency for our stands is shown in Table 5. Falls Creek C6700 was characterized as a stand with low cutstump density

(0.7 stumps/per tree). In contrast, the Palix units D2300 and D2000 averaged 3.8 cutstumps per residual tree. Overall, some 30 percent of the study trees did not have a cutstump within a 3-foot radius. Figure 3 displays a histogram of the varying number of trees with increasing numbers of cutstumps. The frequency of trees decreased rapidly with increasing cutstump classes. The maximum number of cutstumps surrounding a single tree was 17 (Palix D2000).

We found no significant relationship (P = 0.05) between cutstump frequency within 3 feet of residual trees and the tree's risk of infection by *H. annosum*. This is due to the fact that probability of infection did not increase with increasing numbers of cutstumps (Table 6). The average infection probability in cutstump classes up to five stumps per tree was (P = 0.022). No infected trees were encountered in cutstump frequency classes greater than six stumps per residual.

These findings do not support the initial hypothesis that disease initiation increased with higher cutstump frequencies. They indicate that cutstumps may not be the rate-limiting infection factor. This places greater importance on spore loads as a limiting infection factor in our survey stands. Theoretically, infection rates should increase linearly if both spores and cutstumps are not limiting. This is not shown by the data in Table 6.

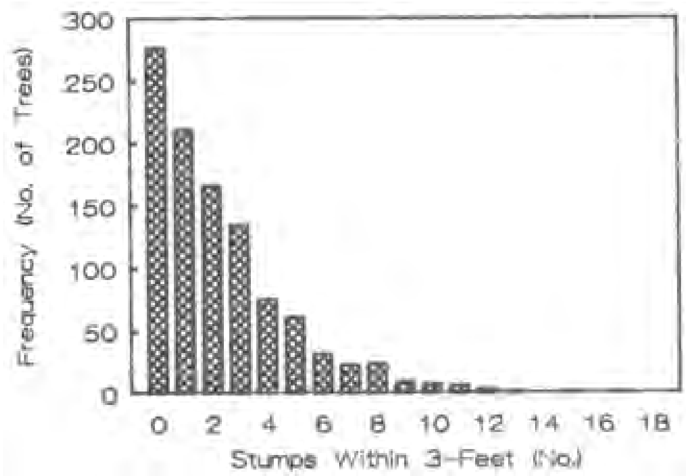

Figure 3--Frequency distribution showing the number of pre-commercially cutstumps within three feet of individual residual western hemlock trees, in stands surveyed for *H. annosum* in Washington State.

Table 5--Summary of disease factors associated with *Heterobasidion annosum* in survey stands of western hemlock, including sporophore occurrence, and mean pre-commercial thinning (PCT) cutstump density around stand residuals

Stand name[1]	Sporophore Occurrence[2]	Cut-stump density[3]
	Percent of area	Mean
Falls Creek C2600	0	1.9
Falls Creek C6700	0	0.7
Falls Creek C6790	0	1.0
Lund A800	0	1.3
Nemah X130	40	2.2
Nemah Y1710	90	2.3
Palix A2100	40	2.8
Palix A2710	40	2.2
Palix D2000	20	3.8
Palix D2300	20	3.8
Trap Creek D920	20	1.4

[1] The letter and number designations that follow the stand names identify the road line (letter) and secondary access road number.

[2] Percent of sample plots with sporophores of H. annosum.

[3] Mean number of PCT-stumps in a 3-foot radius of plot residuals based on ten 1/50th acre plots per stand.

Table 6--The probability of a residual western hemlock in different cutstump[1] classes becoming infected by <u>Heterobasidion annosum</u> following pre-commercial thinning (PCT)

Cutstumps[1] per residual	No. of trees	Infected[2]	Infection probability
no.	total	no.	percent
None	230	5	2.2
1	147	5	3.4
2	115	1	0.9
3	93	2	2.2
4	60	0	0
5	47	2	4.3
6-17	7	0	0
Totals (trees)	769	15	Average 2.0

[1] Number of PCT-stumps within 3-foot radius of individual residual western hemlock.

[2] Number of confirmed H. annosum infected trees.

We suggest that lack of significance between cutstump frequency and infection by <u>H. annosum</u> in this study might be explained by: (1) variable infection rates for different sized stumps, (2) low infection rates under low incident spore loads, and (3) changes in root grafting frequency at different stocking levels, or combinations of the above. The role these variables play in the infection process needs to be quantified.

CONCLUSIONS AND DISEASE MANAGEMENT CONSIDERATIONS

Southwestern Washington currently contains many overstocked stands of western hemlock. Present pre-commercial thinning practices reduce stand stocking to optimize residual tree growth and log size. The increase of root disease caused by <u>H. annosum</u> after thinning has been demonstrated, but its magnitude and impact are still being debated (Edmonds and others 1989).

Currently, no disease-control measures, such as borax-stump treatment, are practiced, as has been advocated in earlier studies (Russell and others 1973). Our results indicate that no control measures are warranted in hemlock stands thinned in the 15 to 20-year-old age class (or younger), and under low infection potential (low sporophore incidence).

Results of this study demonstrated that:

1). Levels of infection caused by <u>H. annosum</u> in residual trees in thinned coastal Washington western hemlock stands are low (0 to 8 percent). Current merchantable volume in decay ranges from 0 to 1 percent. <u>H. annosum</u> was the most frequent cause of root decay in the western hemlock trees in this study.

2). Infection levels were not correlated with slope, elevation, or other stand characteristics.

3). No correlation was found between the frequency of cutstumps and increased individual tree risk to infection by <u>H. annosum</u>.

4). Trees infected by <u>H. annosum</u> occur across a wide variety of diameter classes.

5). No sporocarps of <u>H. annosum</u> were observed in slash-burned units. Fruiting in non-burned units varied from 20 to 90 percent of sample area. No relationship was found between current fruiting occurrence and current levels of infection by <u>H. annosum</u>.

6). "Wetwood" occurred in some 45 percent of the sampled trees and it was not indicative of incipient infection by <u>H. annosum</u>.

7). No disease control measures are warranted for hemlock stands thinned under similar low infection potentials.

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