Factors Affecting Loss and Impact

Impact of Precommercial Thinning on Development of *Heterobasidion annosum* in Western Hemlock[1]

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Abstract: The impact of precommercial thinning of western hemlock (Tsuga heterophylla) on the development of Annosus root and butt rot (caused by Heterobasidion annosum) in coastal Washington has been followed for more than 20 years. Infection of stumps and wounds was high following thinning and there was a high probability of residual tree infection. Eleven years after precommercial thinning tree infection was high, but after 20 years levels of infection were low in both thinned and unthinned stands (averaging <5 percent). Volume losses were even lower (<1 percent). Host tree defense mechanisms, including wetwood, appear to be effective in minimizing losses due to H. annosum. Precommercial thinning did not appreciably increase the incidence of H. annosum in the current rotation but problems could occur in future rotations. Borax treatment of precommercially thinned stumps was not effective in reducing the incidence of H. annosum.

Heterobasidion annosum (Fr.) Bref. causes root and butt rot of western hemlock (Tsuga heterophylla (Raf.) Sarg.) in coastal Oregon, Washington, British Columbia, and Alaska (Wallis and Reynolds 1970; Goheen and others 1980; Shaw 1981). This fungus, which is dispersed via airborne spores, colonizes freshly cut stump surfaces (Edmonds 1968; Russell and others 1973) or wounds created during thinning operations (Hunt and Krueger 1962; Wallis and Morrison 1975). In addition, mycelium spreads to adjacent trees through root contacts (Chavez and others 1980).

Because young western hemlock stands are generally overstocked, forest managers wish to thin them early, often precommercially. Will precommercial thinning of western hemlock increase the incidence of infection by H. annosum? Hadfield and others (1986) suggested that the benefits of precommercial thinning will be considerably greater than any disease losses. Chavez and others (1980), Morrison and Johnson (1978), and Wallis and Reynolds (1970) raised concern that impacts from H. annosum would be greatly increased by precommercial thinnings in western hemlock.

The objectives of this paper are to discuss current knowledge of the biology of H. annosum in western hemlock based on our work over the last 23 years and to determine whether precommercial thinning really creates a problem in current and future rotations. The sites involved in our studies are shown in figure 1 and the discussion that follows is in the context of six questions.

1. Is the inoculum of H. annosum increased in precommercially thinned stands vs. unthinned stands in Washington?
2. Is stump treatment with borax desirable?
3. How long does it take for advanced decay to develop, and what are the volume losses in precommercially thinned stands?
4. How do incipient and advanced decay affect wood quality, pulp yields and paper properties?
5. How much variability is there in virulence among isolates of H. annosum?
6. Will H. annosum be a problem in future rotations?

INCREASE IN INOCULUM IN PRECOMMERCIALLY THINNED STANDS

Spore production and release

Heterobasidion annosum produces both basidiospores and conidia which differ morphologically (Shaw and Florance 1979). Hunt and others (1976) suggested that conidia may be important as airborne inoculum in west coast forests in the United States. Leslie (1983) found that as many as 18 percent of the spores of H. annosum trapped in Washington were conidia, and Hsiang and others (in press) suggested that the aerial spore load of H. annosum may be one-third to one-half conidia. Florance and Shaw (1988), however, trapped only basidiospores in Oregon. We still do not fully understand the role of conidia in the Annosus root disease cycle, although it could be a very important one.

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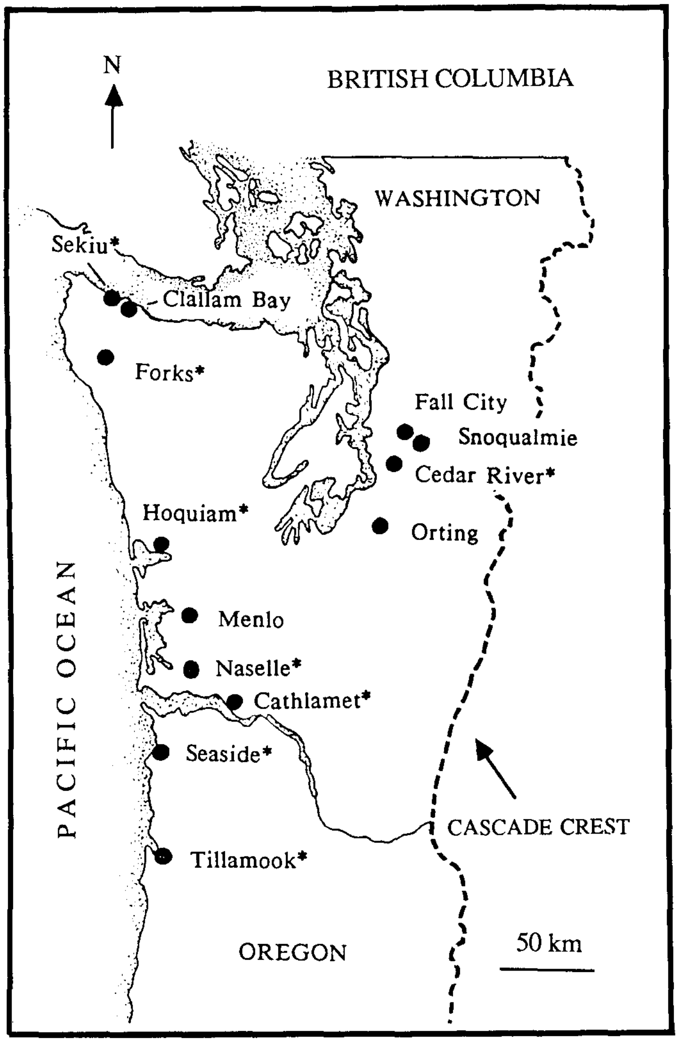

Figure 1--Study site locations in western Oregon and Washington used for research on Heterobasidion annosum in western hemlock.

*spore deposition studied at these sites.

Diurnal patterns of spore release have been observed in western Washington; maximum release is at night although this was not always consistent (Leslie 1983). Other workers have found that wood rotting basidiomycetes tend to have maximum spore release at night. Rockett and Kramer (1974) and Schmidt and Wood (1972) found this to be true for H. annosum in the eastern United States. Spores of H. annosum disperse rapidly at night even at extremely low wind speeds (Edmonds 1971; Edmonds and Driver 1974a; Fritschen and Edmonds 1976).

Seasonal patterns of spore release also have been observed. The highest rates at Hoquiam, Washington, occurred in the fall and the lowest rates occurred in the winter (Leslie 1983). Schmidt and Wood (1972) found that spore release patterns were related to microclimate. At Hoquiam, spore release was inversely related to temperature but not closely related to relative humidity (Leslie 1983). Spore release ceased in August when daytime temperatures exceed 38°C (100°F) (Edmonds and Leslie 1983). Reynolds and Wallis (1966) found that spore production ceased whenever temperatures fell below freezing.

Spore deposition

The range of spore deposition rates in precommercially thinned stands in Washington and Oregon is from 1700 - 20,000 spores $m^{-2} \cdot hr^{-1}$) (Edmonds and others 1984b). Much lower rates (3-70 spores $m^{-2} \cdot hr^{-1}$) were observed in an unthinned stand in Washington, although no sporophores were observed (Edmonds and Driver 1974a). Spore deposit on was higher (maximum rate - 2,100 spores $m^{-2} hr^{-1}$) in an unthinned stand of western hemlock and Douglas-fir in British Columbia with sporophores nearby (Reynolds and Wallis 1966). Lower spore concentrations were obtained when sporophores were not observed. The presence or absence of fruiting bodies is obviously important in determining spore deposition rates. Precipitation also appears to reduce spore deposition rates (Shaw 1981; Morrison and others 1986). Thus, it is not clear whether precommercial thinning changes spore deposition loads; this question needs further investigation. Precommercially thinned stands, however, appear to have higher spore deposition rates than commercially thinned stands (Edmonds and others 1984b).

Diurnal patterns of spore deposition occur in western Washington with highest rates at night and lowest during the day (Edmonds and Driver 1974a; Edmonds and others 1984a). Seasonal patterns of spore deposition also occurred. The lowest rates were in the summer and the higher rates were in the fall, winter and spring (Reynolds and Wallis 1966; Leslie 1983; Edmonds and others 1984b).

Stump and wound infection

Thinning creates fresh stump surfaces that are infection courts for airborne spores of H. annosum. Because of the high spore deposition rates in Washington, Oregon and British Columbia, natural stump infection is generally high, but it ranges from 0 to 100 percent. Stump infection is lower in Alaska (Shaw 1981; 1985) although spore deposition can be high (Shaw 1981). The incidence of stump infection declined with time in a British Columbia study; 5 years after thinning only 3-13 percent of stumps were infected compared to initial levels of 9-87 percent (Morrison and Johnson 1978). This decline was attributed to loss of viability and competition from other basidiomycetes, particularly Armillaria spp.

Stump infection in Washington occurs in all months of the year, but the highest rates occur in spring and summer (Edmonds 1968; Driver and Edmonds 1970; and Russell and others 1973). Interestingly, the lowest rates at both the coastal and Cascade sites occurred in the fall when spore deposition rates were high. All sizes of stumps are infected and the fungus seems to move faster in smaller stumps at least in the summer when temperatures are warmer, but it moves slower in the winter (Edmonds 1968; Edmonds and Driver 1974b).

High stump temperatures are known to inhibit stump infection (Driver and Ginns 1969). However, stump temperatures in Washington are rarely high enough to inhibit stump infection (Edmonds 1968; Edmonds and Driver 1974b), and they may even favor stump infection in the summer. Temperatures are generally not low enough to inhibit stump infection in the winter in the maritime northwest United States. Although fungal competitors such as *Trichoderma* spp. and *Leptographium* spp. are commonly observed on stump surfaces, they are not effective competitors on hemlock stumps (Edmonds 1968). Temperatures are rarely warm enough to favor high-temperature fungi like *Trichoderma* spp. which are effective inhibitors of *H. annosum* in the southeastern United States (Driver and Ginns 1969).

Tree infection

Once stumps are infected, the fungus moves downward into the root system and through root grafts into the stems of healthy trees. The majority of the tree infection in the study by Chavez and others (1980) at Clallam Bay, Washington, was through thinning stumps, but animal damage to roots by mountain beaver (*Aplodontia rufa*) and other wounding were important. Logging wounds also increase the amount of infection in a stand (Hunt and Krueger 1962; Wallis and Morrison 1975; Goheen and others 1980).

Chavez and others (1980) noted that tree infection was most common through residual stumps that were either close or grafted to the remaining crop tree. They estimated fungal growth rates in the trees remaining after thinning to range from 23 to 128 $cm \cdot yr^{-1}$ with an average of 75 $cm \cdot yr^{-1}$. Wallis and Reynolds (1970) reported that *H. annosum* could grow in wood at a similar rate.

Second-growth unthinned western hemlock stands in Oregon, Washington and British Columbia show a range of infection from 3 to 38 percent of total trees sampled (table 1). One stand in the study of Schmitt (1979) was 67 percent infected. Thus, infection levels can be high even in unthinned stands. The source of most of the tree infection probably is root contacts with infected old-growth stumps (Wallis and Morrison, 1975).

Although precommercial thinning results in stump infection, is tree infection really any higher in thinned than unthinned stands? At Clallam Bay, tree infection was 90 percent, 11 years after precommercial thinning at age 15 (table 2). However, 20 years after thinning, tree infection was only 5 percent. In similar precommercially thinned stands at Menlo and Naselle, Washington, infection rates were also low (0 and 4 percent infection, respectively, 15-20 years after thinning) (table 2). This is a very low rate of infection, and at Clallam Bay the amount of tree infection appears to have decreased from year 11 to year 20. How could this occur? We found that 92 percent of the trees in the thinned stand had wetwood in the base. Wetwood is "a type of heartwood in standing trees which has been internally infused with water" (Ward and Pong 1980). Wetwood in western hemlock also has high extractives content and reduced permeability (Schroeder and Kozlik 1972). Properties of wetwood have been shown to form an effective defense against *H. annosum* in *Abies concolor* (Worrall and Parmeter 1983) and in *A. grandis* (Coutts and Rishbeth 1977). We suspect that wetwood in western hemlock is antagonistic to *H. annosum*, holding it in check.

BORAX STUMP TREATMENT

One way of reducing the impact of *H. annosum* in precommercially thinned western hemlock stands is through chemical stump treatment. Many chemicals have been tested including borax (Edmonds 1968; Edmonds and others 1969; Russell and others 1973), sugar borax, sodium nitrate and urea (Edmonds 1968), zinc chloride (Morrison and Johnson 1975), monolaurin (Nelson and Lu 1980), benlate, captan, and wood preservatives (ACA and CCA) (Hu 1984). Borax is probably the easiest to apply and can be effective if applied carefully (Edmonds and others 1969; Russell and others 1973). It is difficult to apply in precommercial thinnings because of the stump density, and it tends to wash off if stumps are not cut horizontally. Twenty-eight percent of the borax treated stumps at Clallam Bay were infected compared to 76 percent of untreated stumps (Edmonds 1968). In addition, we know that the fungus can enter the stand through wounds caused by thinning and animal damage. Thus it is expected that *H. annosum* cannot be totally excluded by stump treatment alone.

Evaluation of borax stump treatment 20 years after precommercial thinning does not reveal that infection levels can be reduced compared to untreated stands (figure 2). *Heterobasidion annosum* infections averaged 4.7 percent for thinned, no-borax plots, 11.2 percent for thinned-boraxed plots, and 2.9 percent for unthinned plots. Differences are not significant between thinned-borax and thinned, no-borax treatments. Operational use of borax in forest stands probably will not provide protection from stand infection.

DEVELOPMENT OF INCIPIENT AND ADVANCED DECAY

Eleven years after precommercial thinning at Clallam Bay, Washington, incipient decay caused by *H. annosum* had extended an average of 4.1 m in height and as far as 11 m in one tree (Chavez and others 1980). No advanced decay was noted in the boles, and infected trees had no external symptoms, although height growth was slightly impaired. Although 90 percent of the trees were

Table 1--Percent infection by *Heterobasidion annosum* in unthinned western hemlock stands in western Oregon, Washington, and British Columbia

Average infection	Stand age (years)	Location	Reference
8	15	Clallam Bay	Edmonds 1968
17	20-60	Coastal Range and Cascade Mountains, Washington	Driver and Wood 1968
38	22-50	Coastal Oregon, Coastal Range and Cascade Mountains, Washington	Schmitt 1979
3	35	Clallam Bay	Shaw and Edmonds unpublished[1]
6	37	Menlo	Shaw and Edmonds unpublished[1]
22	50-60	British Columbia	Blair and Driver 1977
13	40-125	Washington and Oregon	Goheen and others 1980
10	Unknown[2]	British Columbia	Wallis and Morrison 1975

[1]Unpublished data on file, College of Forest Resources, University of Washington, Seattle, Washington.

[2]Tree age range data not available.

Table 2--Percent infection by *Heterobasidion annosum* in precommercially thinned stands of western hemlock in Washington

Average percent infection	Years after thinning	Location	References
90	11	Clallam Bay	Chavez and others 1980
5	20	Clallam Bay	Shaw and Edmonds unpublished[1]
0	15	Menlo	Shaw and Edmonds unpublished[1]
4	20	Naselle	Shaw and Edmonds unpublished[1]

[1]Unpublished data on file at College of Forest Resources, University of Washington, Seattle, Washington.

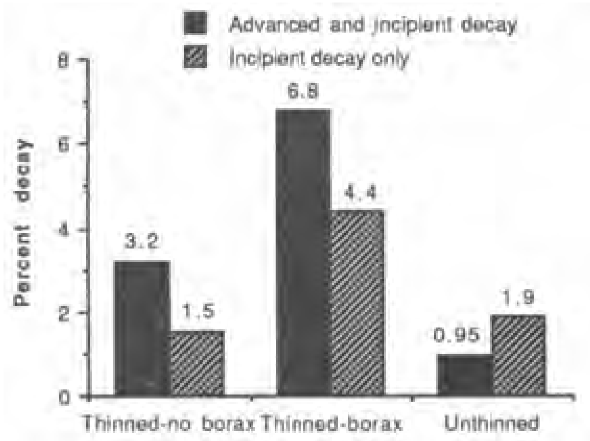

Figure 2--Percent of western hemlock trees with incipient decay only and advanced and incipient decay due to Heterobasidion annosum in precommercially thinned no-borax treatment, precommercially thinned-borax treated, and unthinned stands at Clallam Bay, Washington.

infected, very little merchantable volume (to a 10-cm diameter top) was associated with the incipient decay stain.

The stands at Clallam Bay were revisited 20 years after precommercial thinning to determine whether advanced decay had developed and what losses had occurred. We sampled three 0.04-ha plots each in thinned, no-borax; thinned-borax; and unthinned treatments (see Shaw and others in press for method description). Advanced decay caused by H. annosum occurred in each treatment; 3.7 percent of the trees in thinned, no-borax, 6.8 percent in thinned-borax and 1.0 percent in the unthinned trees (figure 2).

The average height of H. annosum decay was 1.5, 1.0 and 1.3 m in thinned, no-borax; thinned-borax; and unthinned treatments, respectively. The highest decay column extended 3.7 m above ground level.

Volume losses, in terms of percent of volume to a 10-cm (4-in) top in combined advanced and incipient decay, averaged under 0.1 percent for all treatments except thinned-borax, which averaged 0.9 percent (figure 3). In coastal Washington at harvest, western hemlock with basal decay may be long-butted (cut high off the ground to avoid decay). Percent volume losses with long-butted logs are shown in figure 4. Losses are still minimal (less than 1 percent for thinned no-borax and unthinned treatments, whereas the thinned-borax treatment averaged 3 percent).

Volume losses due to advanced decay caused by H. annosum are just becoming realized 20 years after precommercial thinning. The suggestion by Hadfield and others (1986) that losses due to H. annosum will be minimal compared to benefits of thinning appears to be correct.

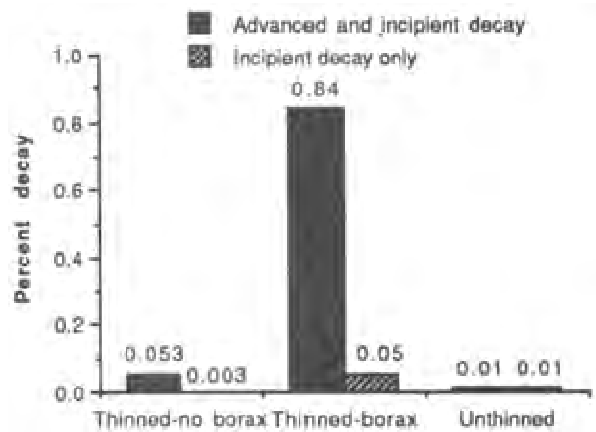

Figure 3--Percent volume loss to Heterobasidion annosum in western hemlock trees with incipient decay only and with advanced and incipient decay in precommercially thinned no-borax, precommercially thinned-borax treated, and unthinned stands at Clallam Bay, Washington.

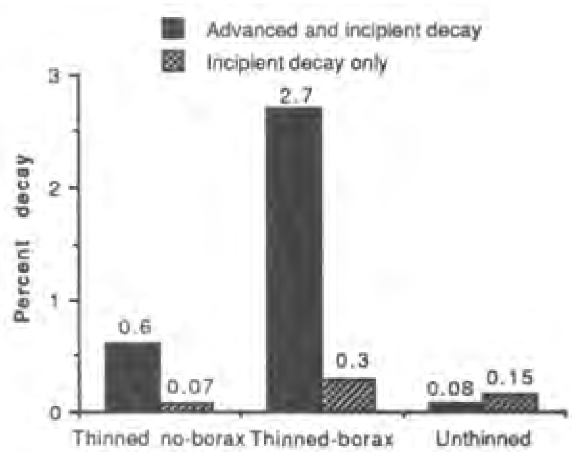

Figure 4--Percent volume loss to Heterobasidion annosum in western hemlock if decayed base is long-butted, for trees with incipient decay only and advanced and incipient decay in precommercially thinned no-borax, precommercially thinned-borax treated, and unthinned stands at Clallam Bay, Washington.

IMPACT OF HETEROBASIDION ANNOSUM ON WOOD QUALITY AND PULP YIELDS AND PAPER PROPERTIES

We have little information on the effects of H. annosum on western hemlock wood quality. There is no current degrade for stain in the domestic market. However, long-butting of export logs with stain is commonly conducted to make them acceptable. Not all of the stain in western hemlock is incipient decay stain, however. Much of it is wetwood. Wetwood may cause differential shrinkage in kiln-dried lumber, and it is associated with ringshake. This is an important area for investigation, and we need more information about the effects of stain to determine its economic impacts on wood quality.

We have conducted preliminary tests on the physical properties of western hemlock wood with incipient and advanced decay caused by H. annosum. Wood with incipient decay did not have reduced strength. However, as expected, wood with advanced decay had significantly lower modulus of rupture (P = 0.01) and modulus of elasticity (P = 0.05).

We do know, however, that pulp yields from incipiently decayed wood are reduced an average of 2-3 percent, and from wood with advanced decay, as much as 8 percent (Driver and others 1984). These reductions in yield could be economically important since a 1 percent change in yield can result in economic loss (W. McKean, University of Washington, Seattle, Washington, personal communication, 6 June, 1985).

Paper properties are also affected by H. annosum decay in pulp wood. Paper apparent density is increased about 6 and 15 percent using wood with incipient and advanced decay, respectively. Tear index (a major index of paper strength) showed the most dramatic change: 20 percent and 40 percent reduction from wood with incipient and advanced decay, respectively. Fiber lengths were shorter and fiber coarseness was lower in wood with advanced decayed. The decrease in fiber coarseness occurs because infection by H. annosum results in thinner cell walls, and this in combination with smaller fiber length explains the dramatic drop in tear strength in paper made from wood with advanced decayed. Thus, H. annosum is likely to increase the amount of culling loss with wood used for manufacturing fiber products.

VARIABILITY IN VIRULENCE OF ISOLATES OF HETEROBASIDION ANNOSUM

Table 1 shows the considerable variation in disease incidence among stands. There is also variation in infection within a stand. For example, Chavez and others (1980) found that the mean growth rate of H. annosum within trees varied from 23 to 128 $cm \cdot yr^{-1}$. Environmental factors such as variation in temperature and moisture, the presence or absence of competing organisms, stand factors (age and diameter of trees, size of wounds), and wood properties can account for some of this variability. Edmonds (1974) attempted to determine whether edaphic factors were related to disease development. Results from a preliminary study suggested that A horizon soil in the vicinity of infected trees is lower in organic matter, has lower pH, and has fewer fungal propagules than similar soil near healthy trees. There was no clear relationship between disease development and percent sand, silt, and clay. Habitat type may also influence disease development. Relationships between environment and disease development, however, need further investigation.

Environmental and substrate quality differences cannot, however, explain all of the observed variation. Some of it is no doubt due to differences in fungal pathogen virulence. Hsiang (1988) reported that isolates of H. annosum from western hemlock trees belong to the S-group (*sensu* Korhonen), and that these isolates were extremely variable with respect to growth and virulence. The largest component of variation in growth occurred within fungal populations. Electrophoresis and cross-plating techniques were used to delimit clones of H. annosum in western hemlock stands. Individual clones were found to be very limited in size and were confined to single trees or even just parts of trees. This indicated the greater importance of aboveground infections caused by basidiospores or conidia over belowground mycelial infections in the spreading of this fungus.

Heterobasidion annosum is physiologically specialized for host trees of different or even the same species based on the production of conidia on branch disks (Hsiang and Edmonds in press). However, there are no full barriers to infections of different host species in populations of H. annosum from western hemlock. There is tremendous variation in the resistance of western hemlock toward H. annosum, but the level of resistance of individual trees is not equal against all isolates.

Considerable variability in H. annosum also exists in culture. Growth rates vary for both linear extension and biomass production. In culture, the linear growth of H. annosum from different geographic locations and even from the same stand varies considerably although the maximum growth rate was always at 25°C (Edmonds 1968). While testing isolates from Alaska to California, Hsiang (1988) did not find adaptation to local temperatures by H. annosum.

Wood decay tests also indicate considerable variability in weight loss between and within sites (table 3). According to the American Society for Testing and Materials (1969), a 12-week incubation test with 11-24 percent weight loss indicates resistance. Thus, the 11-20 percent weight loss recorded by Frankel (1983) on wood blocks from 25-yr-old trees suggests that western hemlock is resistant to H. annosum. Perhaps this explains the relatively low losses to advanced decay in the field. Heartwood extractives from 40-year-old western hemlock, however, were not strongly inhibitory to H. annosum in culture (Edmonds 1976).

Interestingly, isolates from trees experiencing the most damage in the field had the highest weight loss in the soil block test (technique described in American Society for Testing and Materials 1969), i.e., isolates from windthrown trees caused the greatest weight loss (table 3). Lowest weight loss was associated with isolates from incipiently decayed trees. This seems to indicate that differences in pathogen virulence is responsible for some of the observed differences in disease development.

Table 3--Average percent weight loss for western hemlock wood decayed by each of nine isolates of Heterobasidion annosum after 12 weeks in a standard soil-block test (from Frankel 1983)

Isolate number	Isolate location (Washington)	Average percent weight loss (Standard deviation)[1]	Stand condition
1	Orting	20.2 (1.5)[a]	Windthrown[2]
2	Orting	17.1 (1.0)[b]	Windthrown[2]
3	Orting	15.4 (0.8)[c,d]	Windthrown[2]
4	Snoqualmie	11.6 (.5)[f]	Windthrown[2]
5	Fall City	17.7 (0.7)[b]	Windthrown[2]
6	Forks	11.0 (1.4)[f]	Standing[3]
7	Forks	13.2 (0.7)[e]	Standing[3]
8	Forks	14.4 (0.7)[d]	Standing[3]
9	Forks	15.7 (0.9)[c]	Standing[3]

[1]Associated letters indicate Duncan's multiple range test subsets. Numbers with different letters are significantly different (P - 0.05).

[2]Infection with advanced and incipient decay.

[3]1nfection with incipient decay only.

WILL HETEROBASIDION ANNOSUM BE A PROBLEM IN WESTERN HEMLOCK MANAGEMENT DURING FUTURE ROTATIONS?

The inoculum potential of H. annosum is extremely high. Forests in western Washington, Oregon and British Columbia seem to be bathed continuously in spores and only rarely does the temperature become hot or cold enough to inhibit spore release. Year-round, infection rates are high in stumps and wounds created by precommercial thinning. Infection rates in stumps are high in the summer months despite the lower spore release and deposition rates at that time of year. The environmental factors that control stump infection in other regions such as the southeastern United States (high temperatures and microbial competition) and Scandinavia (too cold) rarely operate in low elevation coastal forests in western North America, except perhaps in Alaska where cold temperatures and anaerobic conditions in stumps may inhibit fungus development (Terry Shaw, USDA Forest Service, Juneau, Alaska, personal communication, 9 September, 1986).

Heterobasidion annosum moves quickly from stumps to retaining crop trees at an average rate of 75 $cm \cdot yr^{-1}$ and it causes incipient decay in the majority of trees (in 90 percent of trees 11 years after thinning at Clallam Bay). It also causes incipient decay in unthinned second-growth western hemlock stands, but infection rates appear to be lower than those in precommercially thinned stands (figure 2). Thus, 11 years after precommercial thinning the situation did not look very good. We thought that when we examined the stands at Clallam Bay 20 years after thinning, we would see strong development of advanced decay and considerable volume and economic loss. This did not happen. There was very little advanced decay and volume loss, and in fact it appears that the amount of total tree infection was reduced.

We now believe that regulating factors in western hemlock trees inhibit the development of H. annosum; the wetwood environment which develops in most trees may be too antagonistic for the fungus to exist, or it may be that other microorganisms involved with wetwood outcompete H. annosum.

There is tremendous variability in virulence of H. annosum. The situation at Clallam Bay involved strains that only appear to cause butt rot. Some strains of H. annosum isolated from western hemlock appear to be more virulent than Clallam Bay isolates, for example, those at Orting, Washington, which cause root-rot, blow-down, and butt rot (table 3). In these stands, increased tree infection by precommercial thinning could be a much bigger problem.

What about future rotations? Most thinning stumps are infected and they could serve as a source of inoculum for residual trees. Precommercial thinning stumps are small in diameter, and H. annosum seems to be easily replaced in them by Armillaria spp. and other basidiomycetes. We do not know as yet what species of Armillaria is involved at Clallam Bay, but this will be determined, since it is not desirable to increase the incidence of Armillaria in hemlock stands. Morrison and others (1986), however, classified the Armillaria on western hemlock stumps in British Columbia to be in Group V which is not pathogenic to conifers. Thus, the next rotation does not seem to be particularly at risk from H. annosum existing in precommercial thinning stumps. The larger stumps remaining after clearcut harvesting at the end of the rotation, however, may prove to be a greater risk for inoculum increase.

There is considerable virulence among strains of H. annosum and we know that highly virulent strains exist like the one at Orting, Washington. We also know that strains can show specificity toward particular host individuals (Hsiang and Edmonds in press). Can such virulent and specialized strains spread more widely? To answer this, we need to know more about the role of conidia in the spread of H. annosum. Conidia can retain highly virulent gene combinations, but basidiospores lose those combinations, thus, enhancing variability.

CONCLUSIONS

The direct effect of precommercial thinning of western hemlock stands on infection by H. annosum is to create fresh infection courts, both stump surfaces and tree wounds, for spores to colonize. Once these surfaces are colonized, H. annosum must contend with host tree defenses and competition from other organisms in thinned stumps. It appears that these mechanisms are effective in minimizing losses due to H. annosum within 20 years after thinning. Thinned western hemlock stands do not have significantly more infections than unthinned stands at Clallam Bay.

Our ideas on the effects of precommercial thinning in western hemlock stands have evolved considerably over the last 23 years. Based on experience in Europe and the southeastern United States, we expected that precommercial thinning could dramatically increase H. annosum and that rotation lengths would be "pathological rotations" determined by the amount of butt rot developing in relation to time after thinning. Environmental conditions in Oregon and Washington appeared to be ideal for development of the fungus. Our current evaluation, based on considerable knowledge of the biology of H. annosum, is that the present situation is not as serious as it first appeared to be over a decade ago. Heterobasidion annosum has tremendous capacity to spread. However, it is apparently being held in check at this time by "natural" biological control mechanisms involving wetwood and microbial competitors.

Borax does not appear to be effective for operational use in coastal Washington, although it may be effective if applied very carefully to stumps, particularly those close to the remaining trees. Morrison and others (1986) believe that borax stump treatment should be considered in parts of British Columbia.

The book is not yet closed on H. annosum in western hemlock and the ultimate effect of precommercial thinning on the development of H. annosum remains to be determined. There are still many questions which need to be answered, such as:

- What will be the extent of H. annosum development in stands at rotation age?
- What is the optimum rotation age for western hemlock stands being utilized for lumber or fiber products relative to development of H. annosum decay?
- Will large stumps remaining after clearcut harvesting increase the inoculum potential of a site?
- Can H. annosum produce hypervirulent strains capable of rapid spread in western hemlock forests?
- What is the relationship between wetwood and the development of H. annosum?
- Will wetwood result in product degrade and economic impact?
- What is the relationship between H. annosum and other pathogens such as Armillaria spp. in both thinned and unthinned stands?

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