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MANAGEMENT OF LAMINATED ROOT ROT
CAUSED BY PHELLINUS WEIRII
(MURR.) GILBERTSON IN DOUGLAS-FIR

by

Robert G. Fraser

A PROFESSIONAL PAPER SUBMITTED IN PARTIAL FULFILLMENT OF
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Management of Laminated Root Rot Caused by Phellinus weirii (Murr.) Gilbertson

in Douglas Fir

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ABSTRACT

Laminated root rot caused by *Phellinus weirii* (Murr.) Gilbertson, is a destructive pest in Douglas-fir forests; it causes an estimated annual loss in the Pacific Northwest of 4.4 million m^3 of wood. Research and development on the management and control of *P. weirii* has been ongoing for more than 25 years. Three management strategies have emerged: 1) the site can be sanitized to remove the disease inoculum prior to reforestation, 2) the disease can be contained until the stand is harvested, and 3) the stand can be managed as if the disease were not present. Fallow crops, alternative crops and physical removal of inoculum are currently being used to sanitize infected sites. Other potential management tactics are breeding Douglas-fir resistant to *P. weirii*, and the use of biological agents such as *Trichoderma*, and chemicals such as chloropicrin or glyphosate, to kill the fungus. Containing the spread of the disease in immature stands can be accomplished during thinning operations provided crews are properly trained. Managing infected stands as if the disease were not present is becoming increasingly uncommon, especially in B.C. where new legislation makes current and future recognition and treatment of pests mandatory when harvesting infected stands from crown land. The understanding of *P. weirii* in Douglas-fir forests has increased greatly in the past 40 years. Despite cuts in research funding and the fact that there are only a few researchers investigating *P. weirii*, many of the critical remaining questions are currently being addressed.

INTRODUCTION

Laminated root rot, caused by Phellinus weirii (Murr.) Gilbertson, can be found in most coniferous stands in the Pacific Northwest, and is particularly destructive in second growth stands of Douglas-fir, Pseudotsuga menziesii (Mirb.) Franco (Buckland et al. 1954, Wallis 1976). Mortality in young stands is scattered and trees are small. From age 40 onward, however, the problem is often conspicuous and volume losses can be substantial (Nelson et al. 1981). More importantly, once established on a site, the disease persists from one rotation to the next in roots and stumps and if left unchecked will substantially lower site productivity (Nelson et al. 1981). Furthermore, common cultural practices, such as clearcutting and replanting with Douglas-fir enhance the spread of the disease and intensify its impact.

Despite the importance of P. weirii, forest managers have only recently begun to take action to manage the disease. Legislation is now in place in B.C. which makes recognition and control of pests such as P. weirii mandatory on crown land. (B.C. Min. of For. and Lands. 1988b.) In addition, forest companies operating on private land are also developing strategies for P. weirii control.

One of the main reasons it has taken over 40 years to recognize the importance of P. weirii is the lack of quantitative data on volume losses attributable to this disease. Only two of the published volume loss estimates describe the method by which they were derived (Table 1). Without such quantitative studies, which demonstrate a need for research,

TABLE 1. Volume and productivity losses to Phellinus weirii in the Pacific Northwest.

Source	Loss Estimate
Childs and Shea (1967)	0.9 million m^3/yr in Douglas-fir forests on the west side of the Cascade Mountains; estimate was a consensus of four forest disease specialists using data from 1958 U.S.Forest Service Timber Resource Review supplemented by updated, measurements of forest volumes, growth rates, and disease effects.
Wallis (1967)	3.2 million m^3/yr in the U.S.; first put forth by Childs and Shea (1967) as annual loss to P. weirii, Armillaria mellea (Fr.) Karst.and Fomes annosus (Fr.) Cke. in Washington and Oregon. 1 million m^3/yr annual mortality in British Columbia; no method described.
Wallis (1976)	annual losses to mortality in British Columbia exceed 1 million m^3/yr; no method described.
Nelson, et al (1981)	annual loss to mortality of 4.4 million m^3/yr in the Northwestern United States and British Columbia; no method described.
B.C. Ministry of Forests (1986)	annual losses to mortality of 238,000 m^3/yr for Vancouver Forest Region, 361,000 m^3/yr for province (area in Tree Farm Licenses excluded); regression equations developed from data collected on over 6000 ha of ground surveys applied to provincial forest inventory data.
Anonymous (1986)	annual mortality of 1.3 million m^3/yr in British Columbia; no method described.

proven control methods have been slow in coming. While many questions remain unanswered, much is known about P. weirii. Research in the past 25 years has addressed the disease's biology, ecology, detection and most recently, control. Some aspects of this work have been reviewed by others (Ward 1979, Thies 1984). This paper reviews what is known about P. weirii in Douglas-fir forests. Current research and operational guidelines, primarily for B.C. forests, are presented. Future research needs are also discussed.

BIOLOGY AND ECOLOGY

Despite being native to the Pacific Northwest, *P. weirii* was not recognized as a root disease of Douglas-fir until the late 1920's (Wallis and Reynolds 1965, Nelson et al. 1981). Furthermore, until 1940, the causal agent was unidentified. In that year, Mounce et al. (1940) described the fungus as a form of *Poria weirii* (Murr.), a fungus known to cause common rot and butt rot in western redcedar *Thuja plicata* Donn. Finally, Gilbertson (1974) placed the species in the genus *Phellinus* where it remains to date.

Symptoms of *P. weirii* infection in Douglas-fir are similar to those caused by other root pathogens. Initially, tree crowns become thin and yellow. As the disease progresses, growth on the terminal leader and branches progressively shortens. In the final stages of the disease, numerous small cones (distress cones) are often produced on the dying tree (Nelson et al. 1981).

Quite often root systems of infested trees are so weakened structurally that the trees are windthrown before crown symptoms are evident. Because of death of the large primary roots, and the progressive growth, dieback, and regrowth of adventitious roots, these trees are characterized by their typical "root-balls" (Foster and Wallis 1974, Nelson et al. 1981).

The early stage of decay appears as a red-brown stain in the outer heartwood. Infection rarely extends more than 2 - 3 m up the bole in living trees. Later, the stained wood becomes soft, and small oval pits, about 1 mm in length, appear. At this point, the wood tends to separate (laminate) along annual rings, hence the common name laminated root rot. Accumulations of thin, velvety layers or sparse tufts of brown setal hyphae can be found between the sheets of decayed wood, a diagnostic feature of this disease. Finally, the wood becomes a stringy mass and the lower bole becomes hollow. Decay can continue up into the bole while the tree is standing or after it is windthrown (Foster and Wallis 1974, Nelson et al. 1981).

The fungus remains viable in stumps and large roots for decades, providing the major source of future inoculum. As new trees grow, their elongating roots contact these inocula, resulting in infection. Following initial infection of a root, ectotrophic mycelium spreads proximally and distally along the bark surface usually well in advance of endotrophic mycelium in the wood itself (Foster and Wallis 1974, Bloomberg and Reynolds 1982). Infection of adjacent, healthy trees occurs when their roots come in contact with diseased roots, creating a characteristic expanding circle of infected trees around a source of inoculum. Mycelium can invade roots of harvested trees for at least 12 months, thus increasing the inoculum load in infected areas (Wallis and Reynolds 1965), however, the current feeling among researchers is that the occurrence of this phenomenon is rare.

Spread of mycelium through natural soil is minimal. Also, transmission of the disease by spores has not been demonstrated (Foster and Wallis 1974). When present, sporophores appear as brown, crust-like layers on upturned roots and on the undersides of decayed logs. When sporophores are fresh, they are light buff in color, with a white margin. Later, they turn a uniform dark brown. The exposed surface of the sporophore is poroid, and the pores are small and regular in outline (Foster and Wallis 1974, Nelson et al. 1981). Because they occur infrequently and are inconspicuous, sporophores are of limited value in identification of the disease in the field (Nelson et al. 1981).

Trees infected with _P. weirii_ occur in patches or centers that may involve only one or two trees or may cover areas up to a ha or more. Scattered individuals and small groups of dead trees become evident in plantations 15 to 20 years old. By the age of 40, infested stands usually have obvious centers (Thies 1984). Based on an average rate of spread of about 34 cm per year (Nelson and Hartman 1975), one can expect the number of infected trees in a stand to double about every 15 years (Nelson et al. 1981). Susceptible species of all sizes and ages are attacked; however, damage to individual trees is largely dependent on the age of the tree when first attacked. Trees <10 years old are usually killed soon after their roots contact inoculum. Older trees may sustain significant growth loss for up to 30 years after infection before succumbing to the disease. Douglas-firs that become infected after they are 40 years old are unlikely to be killed by the disease before they would normally be harvested (Hadfield 1985), unless they fall victim to windthrow which in many stands accentuates mortality.

Soil and humus depth, soil texture and soil moisture are known to influence the survival and spread of _P. weirii._ However, correlation of disease incidence and severity with specific ecosystems is not fully understood. In the summer of 1987 a study was initiated by J.D. Beale, a Forest Pathologist with the B.C. Forest Service, to investigate relationships between P. weirii and coastal Douglas-fir ecosystems (Beale 1987b). This study involves using a basal area reduction sampling method to characterize disease incidence and severity in permanent sample plots within managed and unmanaged Douglas-fir stands which have been ecologically described (Klinka et al. 1979).

Preliminary results suggest that P. weirii has a very high incidence but low severity in slightly dry to slightly moist redcedar/Douglas-fir and redcedar/western hemlock (subzone 1) ecosystems. Both incidence and severity appear to be low in dry and wet ecosystems. Infection severity appears to be highest in slightly moist to moist ecosystems, but with lower incidence (Beale 1987b).

DETECTION AND DAMAGE APPRAISAL

Considerable effort has gone into the development of detection and damage appraisal methods for *P. weirii* in Douglas-fir forests. Research and development has focused on ground survey methods, detection using remote sensing techniques and on computer simulation models.

Ground Surveys

In a series of four reports Bloomberg et al. (1980a, 1980b) and Bloomberg (1983a, 1983b) describe five derivations of a transect line sampling system which could be used to estimate incidence, distribution and area of *P. weirii* infection accurately. Common to all derivations of Bloomberg's transect line system were "sets of equidistant, parallel transect lines traversing a stand from one boundary to the opposite one. Each set of transect lines, called a grid, commences from a randomly chosen point on a baseline, running at right angles to the baseline" (Bloomberg et al. 1980b).

Until the development of the Bloomberg method, sequential sampling, random sampling using 20 tree quadrats, prism plots and belt transects had all been tried, and were found to provide varying degrees of precision (Bloomberg et al. 1980a). While the Bloomberg method yielded statistically valid estimates of root infection it was found to be cumbersome and often confusing to field personnel.

In an effort to define a simpler procedure for use in root disease inventories on a regional basis, the B.C. Forest Service developed a modified version of the Bloomberg method (Beale and Wood 1985). This method standardizes the number of lines per grid and transect starting points. Sketch mapping procedures were also included, which allows survey crews to make a complete assessment of root disease infection for management purposes.

Recently a post-harvest intersection length method has been developed by Sterling Wood Group Inc. under contract to the B.C. Forest Service. While this post-harvest method has application in rehabilitation areas where the only inoculum remaining on the site is in old-growth stumps, the two pre-harvest methods, the intersection length method and the sketch mapping method, are the most commonly used ground survey methods in B.C. To date, several thousand ha have been surveyed for _P. weirii_ infection. Cost per ha currently ranges from $15 to $30 depending on terrain and amount of disease present.

Remote Sensing

Aerial photography has been used successfully in the detection of _P. weirii_ (Williams 1973, Johnson and Wear 1975, Williams and Leaphart 1978, Wallis and Lee 1984). Scales as small as 1:31,680 have been used to detect large, well-developed disease openings in stands in the Cascade Range (Johnson and Wear 1975). In Coastal stands, large scales are required because the ground cover usually obliterates many details of infection centres (Wallis and Lee 1984). Wallis and Lee (1984) report that _P. weirii_ could be detected accurately in a Douglas-fir stand nearing maturity (>100 years old) using color photography at scales not greater than 1:15,000. In a very young stand a scale of

1:5000 was required to give a reasonable degree of precision. Disease centres were difficult to detect in a 40 year-old stand, even at a scale of 1:1500. Wallis and Lee (1984) did add, however, that disease symptomatology varies dramatically among middle-aged stands and that accurate estimates of disease distribution can be obtained at scales from 1:6,000 to 1:15,000, provided the disease has created large openings or if dead, standing trees are present in most centres. Several types of film have been tried in *P. weirii* detection studies (Wallis and Lee 1984). Generally speaking, color is superior to black and white photography for *P. weirii* detection. Color-infrared film has some advantage over color film when atmospheric haze is present, or when it is desirable to observe ground details within disease centres (Wallis and Lee 1984). However, even with the largest operational-scale, aerial photography, it has not been possible to observe previsual symptoms of tree distress caused by root disease fungi using color or color-infrared film, manually interpreted (Weber and Wear 1970, Wallis and Lee 1984).

Recent advances in software now allow for computer-aided interpretation of aerial photography. Digitized images have been used successfully to detect other pest occurrences such as Douglas-fir tussock moth defoliation and Dutch elm disease. Computer-aided interpretation is faster than manual interpretation, and in many cases is more precise (J.M. Lee,[1] pers. comm.). Lee is presently investigating the use of a software package called Perception Image

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[1] Research Scientist, Pacific Forestry Centre, Forestry Canada, Victoria, B.C.

Analysis System (PIAS) to identify root disease centres in a variety of stand conditions. Another advance in computer technology is the development of Geographic Information Systems (GIS); if integrated with an IAS, a GIS can automatically update forest cover maps, and provide area of infection and volume loss estimates from pixel classification.

Another remote sensing technique undergoing tests in coastal B.C. is the MEISS-II high-performance digital, multispectral spectrometer (Beale 1988). Mounted on a Falcon jet aircraft, the spectrometer can give spatial resolution as low as 1 m². In 1988 a large block of coastal Douglas-fir in the Powell River Forest District was used as a test area. Airborne sampling was done to provide two levels of spatial resolutions of 4 m² and 1 m². The test area had been previously 100% sketch mapped to allow for groundproofing of the airborne MEISS sampling. The data are being analyzed by J. M. Lee at The Pacific Forestry Centre using the IAS and a GIS system developed by PAMAP Graphics Ltd., Victoria, B.C. If successful, MEISS-II could allow large forest areas to be surveyed for P. weirii at a fraction of the cost of ground surveys.

Damage Appraisal

There are currently three computer models available in the Pacific Northwest designed specifically for P. weirii damage appraisal. The first is PROGNOSIS (Stage 1973). This is a distance-independent, individual tree model developed in the early 1970's by researchers at the Inter mountain Forest and Range Experiment Station, U.S.D.A. Forest Service, Ogden, Utah. This model has a sub-model designed specifically by Environmental and Social Systems Ltd., Vancouver, B.C., under contract with the U.S. Forest Service for laminated root rot. The submodel simulates disease spread, and when combined with PROGNOSIS, it calculates the impact on stand growth, yield and mortality. The model is currently being used by U.S. Forest Service silvicultural planners on an operational scale. The B.C. Forest Service is also interested in this model and is presently calibrating it for interior Douglas-fir stand conditions (B.C. Ministry of Forests and Lands 1988a).

The second model is ROTSIM (Root Rot Simulation). This model was developed by W.J. Bloomberg, at The Pacific Forestry Centre, Forestry Canada. When combined with TASS (Tree and Stand Simulator), ROTSIM incorporates the action of laminated root rot in managed stands of coastal Douglas-fir. ROTSIM can also be linked with a program called BUCK which produces logs from an infected stand, SAWSIM, a program which cuts lumber from these logs, and FANSY, a program which determines the discounted net revenue from tending, harvesting and processing an infected coastal Douglas-fir stand.

The B.C. Forest Service is presently working to have ROTSIM and TASS linked in a format which will allow them to be run on personal computers at the regional and district level (B.C. Ministry of Forests and Lands 1988a).

The final model is RREST (Root Rot Estimator). This simple statistical model has also been developed by Bloomberg (1983a). The program, which is written in FORTRAN IV Plus, uses estimates of P. weirii spread rate and impact on tree growth, either supplied by the user or default values already built in to the program, to predict increases in infested area, and reduction in volume in coastal Douglas-fir stands after a specified number of years. The model also produces simulated transect surveys of infested stands for comparison with ground surveys. Results can be printed as tables, maps and graphs. To date the model has had limited operational use; however, utilization should increase now that the program has been converted for use on personal computers.

MANAGEMENT STRATEGIES AND TACTICS

A management strategy is a plan designed to meet specific objectives. Tactics are specific tools and/or techniques used to make the strategy work.

In the most general sense, the three management strategies that are potentially possible when a stand is infected with P. weirii are: 1) the site can be sanitized by removing the inoculum from the soil, or by allowing it to die or killing it therein, 2) the site can be managed to contain the spread of the disease, and 3) the site can be managed as if the disease were not present.

Present Guidelines

Changes in forest policy in British Columbia, which came into effect in March 1988 (B.C. Min. of Forests 1988b), have meant that all pests, including P. weirii, must now be recognized and treated on crown land. Before an area is logged, a pre-harvest silviculture prescription must be completed for the area. This prescription sets out how and when the area will be logged, reforested and managed during the next rotation. An assessment of occurrences and a plan to deal adequately with each pest must also be included in the prescription. Guidelines for detection and treatment of P. weirii are now in place for the Vancouver Forest Region (Beale 1987a). With the aid of these guidelines, site-specific plans can be made to reduce the impact of P. weirii to an acceptable level.

Another change in forest policy made in 1987 (B.C. Min. of For. and Lands 1987b) shifted silvicultural costs from government to industry. Allowances for most silvicultural costs have been incorporated into the appraisal system (the process by which the stumpage payable to the crown is derived). However, allowances were initially not included for stump removal for pest management purposes. This specific problem may soon be rectified, as the Ministry of Forests, Valuation Branch, is considering including allowances for stumping costs in timber appraisals. Other pest management costs will doubtless pose similar problems in the future.

State Of Research

Research on P. weirii has been ongoing for about the past 25 years in the Pacific Northwest. The majority of this research has been completed by a small group of researchers whose resources and funding have been limited.

In 1986, a Task Force on Root Disease Research submitted a report to the Forest Pest Review Committee (chaired by Mr. J.R. Cuthbert, R.P.F., Chief Forester for the province) which summarizes 1985/86 expenditures for all aspects of forest pathology research in B.C. (van der Kamp et al. 1986). Only two agencies, the Pacific Forestry Centre (Forestry Canada) and the University of British Columbia, had funding allocated for forest pathology research. From the total budget of $7.2 million, the Pacific Forestry Centre spent $259,000 (3.6%) on the investigation of diseases, one of which was P. weirii. The University of British Columbia spent roughly $60,000 or 2.6% of its total forestry research budget of $2.3 million on diseases. Again, P. weirii was only one of many diseases investigated. In 1989/90, only 1% of the total budget at the Pacific Forestry Centre was allocated for root disease research (G.E. Miller,[2] pers. comm.) At U.B.C., no money was allocated specifically for root disease research (B. van der Kamp,[3] pers. comm.) At present the Research Branch of the B.C. Ministry of Forests does not have a research program for diseases. Regional and some District staff are involved in extension and demonstration work. Their work is associated with identification of disease symptoms, survey techniques and demonstration of possible management tactics which in most cases are not fully tested.

With respect to industry, only a few companies have had any involvement with P. weirii in a research capacity. Canadian Pacific Forest Products Limited in 1986, in cooperation with Forestry Canada established a trial to investigate possible control of P. weirii using glyphosate. However, as little or no glyphosate residues were detected in treated roots even five months after treatment, the trial was abandoned. MacMillan Bloedel Ltd. was interested in studying tissue culture as a means of screening trees which are resistant to P. weirii. However, a study has not yet been initiated.

In the U.S.A. a similar situation exists. While some short-term research studies are being conducted by universities and the U.S. Forest Service in Washington and Oregon, most of the effort is in

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[2] Program Director, Forest Protection Research, Pacific Forestry Centre, Forestry Canada, Victoria, B.C.

[3] Professor, Faculty of Forestry, University of British Columbia, Vancouver, B.C.

extension work. Activities involved include promoting awareness, surveys, and as in Canada, facilitating control operations which may or may not be effective from either a biological or economic standpoint (van der Kamp et al. 1986).

Research on _P. weirii_ may be encouraged by the establishment in 1988 of a _Phellinus_ root rot management cooperative in B.C.(Kumi 1988). Participants in the cooperative include researchers from various government agencies, universities and the forest industry. The main objective of the cooperative is to serve as a vehicle for collaborative disease research. Other objectives include serving as a clearinghouse for information, a vehicle for funding, and a lobby for research on root diseases.

STATUS OF MANAGEMENT STRATEGIES AND TACTICS

Sanitation

A sanitization strategy would normally be implemented immediately after an infected stand was harvested, and could be either a long or short term proposition.

FALLOW CROPS OR ALTERNATIVE SPECIES

Allowing an infested site to remain fallow under a cover of non-susceptible species for at least one rotation, or to produce a commercial crop from such a species, would be considered long term. Physically removing the inoculum from the soil immediately after harvesting, or killing the fungus with some type of chemical or biological agent would be considered short term. The latter tactics would allow rapid reforestation with susceptible species like Douglas-fir.

The tactic of allowing a site to remain fallow under uncommercial species for one rotation (>50 years) is economically unjustifiable in most instances. Until recently, red alder, <u>Alnus rubra</u> Bong., has been one of these non-commercial species on the B.C. coast. It had value as firewood, and as wood for low grade furniture, and some specialty products (Warrington 1988). However, recently an export market has developed for alder chips for pulping plus a domestic market for sawlogs (K.A. Donkersley,[4] pers. comm.). Alder chips are currently

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[4] Superintendent, Forestry and Minor Forest Products. Canadian Pacific Forest Products Limited, Qualicum Beach, B.C.

valued at around \$43/m^3 of chips. Alder sawlogs can go as high as \$35/m^3 (K.A. Donkersley,[4] pers. comm.). If these markets remain stable the possibility of using alder as a viable sanitation tactic can be realized. Other species, such as black cottonwood, <u>Populus trichocarpa</u> Torr. and Gray, which are immune to <u>P</u>. <u>weirii</u> and previously considered uneconomic, can also be used to fallow infected sites.

In coastal B.C., there are only two coniferous species which are tolerant or resistant to <u>P</u>. <u>weirii</u> and have the potential to generate revenues comparable to those generated by Douglas-fir (Table 2); they are western redcedar, <u>Thuja plicata</u>, and western white pine, <u>Pinus monticola</u> Dougl. Average log prices published by the Council of Forest Industries for March 1988 indicate that H grade Douglas-fir is valued at \$70.21/m^3, while J grade cedar, a comparable log size, which could be grown in roughly the same time, is valued at \$57.10/m^3. An H grade pine, which includes all species of pine, is valued at only \$24.87/m^3. This value is low for two reasons: 1) there is not a strong demand for pine in the marketplace, and 2) the volumes being produced at present are comparatively low. This disparity could change with time, and it is generally felt that as more white pine reaches harvestable size, the price will increase accordingly.

There is also the problem of site suitability for these two alternative species. Whereas Douglas-fir can be grown on a wide range of sites, from hydric to moderately xeric and from sea level to roughly 1500 m, western redcedar and white pine are site specific. Western redcedar should not be considered on drier sites. Conversely western white pine should not be considered on wet sites.

TABLE 2. Susceptibility of Pacific Northwest tree species to laminated root rot (adapted from Hadfield 1985)

Susceptibility category	Species
Susceptible	Pacific silver fir, _Abies amabilis_ (Dougl.) Forbes Grand fir, _Abies grandis_ (Dougl.) Lindl. Douglas-fir, _Pseudotsuga menziesii_ (Mirb.) Franco Mountain hemlock, _Tsuga mertensiana_ (Bong.) Carr.
Intermediately susceptible	Subalpine fir, _Abies Lasiocarpa_ (Hook.) Nutt. Western larch, _Larix occidentalis_ Nutt. Engelmann spruce, _Picea engelmannii_ Parry Sitka spruce, _Picea sitchensis_ (Bong.) Carr. White spruce, _Picea glauca_ (Moench) Voss. Western hemlock, _Tsuga heterophylla_ (Raf.) Sarg.
Tolerant	Lodgepole pine, _Pinus contorta_ Dougl. Western white pine, _Pinus monticola_ Dougl.
Resistant	Ponderosa pine _Pinus ponderosa_ Laws. Western redcedar, _Thuja plicata_ Donn.
Immune (hardwoods)	Bigleaf maple, _Acer macrophyllum_ Pursh Red alder, _Alnus rubra_ Bong. Pacific madrone, _Arbutus menziesii_ Pursh Black cottonwood, _Populus trichocarpa_ Torr. and Gray Trembling aspen, _Populus tremuloides_ Michx.

Two additional problems exist with white pine, the availability of stock, and the susceptibility to white pine blister rust caused by Cronartium ribicola J.C. Fisch, ex. Rabh. In 1986, only 1.0% of all the seedlings planted in those forest regions of the province where P. weirii and Douglas-fir occur together were white pine (B.C. Min. For. and Lands 1987a). White pine is highly susceptible to white pine blister rust. Although there is an ongoing breeding program in the province (Hunt 1988) and similar breeding programs are being conducted in the United States (Franc 1988) it will be at least 20 years before resistant seedlings will be available (Anon. 1986). In the interim, foresters must rely on seed from "plus" trees which are "believed" to be resistant.

PHYSICAL REMOVAL = MECHANICAL CONTROL

Initial attempts to remove P. weirii-infected stumps was done with bulldozers with solid blades, and amounted to essentially land clearing. However, this method displaced too much soil and left large holes where root systems had once been (Thies 1984). Subsequent attempts used bulldozers with toothed, brush blades.

The oldest operational trial to study the effects of removing P. weirii was established by Forestry Canada in the B.C. interior near Kamloops in 1968 L.C. Weir (Morrison et al. 1988). In that trial the trees in a 1.28 ha block were pushed over with a Caterpillar D8 bulldozer and were yarded to the landing with roots attached. Before planting with a variety of tree species (including Douglas-fir) the soil was root-raked to a depth of 45 cm. Another 1.28 ha block was logged and planted with the same species to serve as a control. Pre-treatment examination of stumps revealed that 60-70% were infected with P. _weirii_. In 1987, 19 years after planting, cumulative mortality of Douglas-fir due to P. _weirii_ in the control area was 4.7% as opposed to 0.2% in the root- raked blocks. In addition, both height and diameter at breast height (dbh) were significantly higher in the treated blocks (Morrison et al. 1988).

The oldest stumping trial on the B.C. Coast was established in 1972 by Forestry Canada near Lake Cowichan. Again a Caterpillar D8 bulldozer with a brush blade was used to uproot and pile P. _weirii_-infected stumps and other debris for burning prior to planting with Douglas-fir on a 1 ha block. Pre-treatment inspection of stumps revealed that 70% were infected. In 1986, 13 years after planting, mortality was 7.3% in the unstumped control area and 1.4% in the stumped area.

While preliminary results from these trials are encouraging, many questions still remain unanswered with respect to the long-term effectiveness of stump removal, and whether or not site productivity would be reduced due to soil disturbance and compaction. Some of these questions have been answered as a result of a trial established by Forestry Canada and MacMillan Bloedel near Lake Cowichan in 1985 (Bloomberg and Reynolds 1988). In that trial, which had a pre-treatment infection level of 20%, three types of equipment were tested: a Caterpillar D8 bulldozer with a brush blade, a small backhoe (115 hp) and a large backhoe (180 hp). Soil pits (roughly 0.5 m wide and 1.0 m deep) were dug in randomly selected points over the 4 ha trial in both treated and control areas. Numbers of root pieces, length and volume per m^3 of soil were calculated. While all three machines effectively removed large amounts of root material, 92, 93 and 94% of total root volume for the bulldozer, small backhoe and large backhoe, respectively, the large backhoe was the most effective in reducing inoculum levels, as more small-diameter, infected roots were removed (Table 3).

TABLE 3. Effect of three types of stump uprooting equipment on the percentage of infected root residue remaining after treatment (adapted from Bloomberg and Reynolds 1988).

	Percent of residue infected[a]		
Treatment	Pieces	Length	Volume
D8 Cat	14.2 a	11.4 a	46.6 a
Small backhoe	4.3 a	3.8 b	22.2 b
Large backhoe	8.6 a	5.3 b	6.7 c

[a] Column means followed by different letters are significantly different, Duncan's LSD test, P = 0.05.

The amount of soil disturbance created by each machine was also measured. In general, the tracks of the bulldozer tended to cause more disturbance than either of the backhoes; deep gouges (over 25 cm) as distinct from deposits were markedly less prevalent in areas treated with the large backhoe (Bloomberg et al.)[5]

Pre- and post-treatment soil bulk density measurements were made for each machine. All machines slightly reduced soil bulk density in the upper 20 cm of the soil profile. These reductions were not considered to be severe enough to decrease site productivity (Bloomberg et al.)[5]

As a result of these and other trials, mechanical stump removal is beginning to be accepted as a valid means of sanitizing sites from _P. weirii_ in certain types of stands. Present guidelines developed by the B.C. Forest Service recommend that stump pulling be considered only on relatively level terrain (slope <35%), with deep, dry and coarse-textured soil (Beale 1987a). From a cost benefit viewpoint, stumping should only be considered on high site land, where returns from a high volume crop would offset the initial cost of stump removal. Currently, the cost for stump removal ranges from $800 to $1200 per ha. Along with the lack of long-term efficacy data, the high cost of this treatment has prevented stump removal from being done operationally on a wider scale.

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[5] Bloomberg W.J., R.B. Smith, G. Reynolds, E. Wass, T.P. Rollerson, D.A. Dunkley and M.K. Hooper. Undated. Effectiveness, soil disturbance and soil compaction, in stump-uprooting equipment trials on a _Phellinus_ root rot-infested cutover. Forestry Canada, Pacific Forestry Centre. Unpublished manuscript.

Research is continuing on developing less expensive ways to remove infected root material from the soil mechanically. One method which requires further testing is whole tree logging which was first used in the Skimikin trial in 1968 (Morrison et al. 1988). By using a large bulldozer to push trees over, root systems are also removed at the same time, thus avoiding a re-entry onto the site with heavy machinery after harvesting has been completed.

BREEDING FOR RESISTANCE

Within any plant population, there are certain individuals which are more resistant to pests than others. Until recently, little attention has been paid to pest resistance in forests. There are currently second generation seed orchards in B.C. producing large amounts of seed for reforestation. However, the parent material was selected primarily for superior height growth and stem form characteristics. It is quite valid to question whether or not this program is creating a population of "super" trees that are highly susceptible to P. weirii and/or other major pests.

Investigations into resistance by Douglas-fir to P. weirii were initiated in 1987 by G.D. Jensen of Forestry Canada (Pacific Forestry Centre 1987, 1988). One possible benefit derived from this work would be a reliable screening technique which could be used to test seed orchard trees for resistance to P. weirii prior to harvesting seed from them. Jensen's investigations centre around identifying mature Douglas-fir exhibiting apparent resistance to infection by P. weirii or recovery from its attack. In 1987, cuttings from 18 trees were rooted.

In 1988, these cuttings were used in histological investigations to study host-pathogen interactions under controlled inoculation and defined conditions. It is hoped that these investigations will identify the basic mechanisms conferring resistance, and will add to an understanding of resistance mechanisms which have already been identified, such as the development of adventitious roots.

BIOLOGICAL CONTROL

Trichoderma

Attempts at biological control of P. weirii have centered around work with fungi, Trichoderma spp., and at least three species of soil-borne bacteria.

There is considerable evidence for the biocontrol of numerous wood-decaying fungi through the introduction of Trichoderma spp. before or at the same time as the pathogen (Nelson and Thies 1985). Invasion of stumps by Heterobasidion annosum (Fr.) Bref. in Finland was prevented by inoculating the susceptible stumps with Trichoderma spp. (Kallio and Hallaksela 1979). Tree wounds have been reported to be protected from invasion by wood destroying fungi when inoculated with various Trichoderma spp. (Smith et al. 1981, Mercer 1982). However, there is little evidence for biocontrol using Trichoderma spp. when the pathogen is well established in the wood (Nelson and Thies 1985).

E.E. Nelson and W.G. Thies, at the Pacific Northwest Forest and Range Experiment Station, U.S.D.A. Forest Service, Corvallis, Oregon are currently investigating the possible control of P. weirii by inoculating infested Douglas-fir stumps with various isolates of

Trichoderma viride Pers: Fr. (Nelson et al.1987). *T. viride* was chosen as the test species based on frequency of isolations made from roots of fumigated and untreated stumps. These stumps were part of a trial established in 1981 to investigate fumigation as a potential control for *P. weirii* (Nelson et al. 1987). In 1984, trials were established whereby groups of uninfested, stained and decayed stumps were inoculated at different times of the year with one of three isolates of *T. viride* in one of two formulations.

Colonization success was significantly better in decayed wood (38%) than in stained wood (29%) or sound wood (7%) and improved with closer proximity to stump top (48% in the top 10 cm, 27% from 10-20 cm, 2% from 20-30 cm) or inoculation hole (47% in wood adjacent to inoculation hole, 21% at 6 cm) (Nelson and Thies 1985). *Trichoderma* spp. were recovered from 29% of wood chips sampled from stumps treated in October, 23% of June-inoculated samples and only 12% of February-inoculated samples (Nelson and Thies 1986).

Colonization by *T. viride*, was better (36%) in stumps inoculated with sterilized barley grains, diatomaceous earth, molasses and water than with birch dowels containing *T. viride* (24%). There were no significant differences among the three isolates tested (Nelson and Thies 1985).

Future studies with *Trichoderma* spp. will focus on variation in antagonism of isolates under controlled conditions, inoculum formulation and timing of application with fungistatic or nutritional compounds (Nelson and Thies 1986).

Although differences in colonization found in these studies are interesting, significant improvement is needed if *Trichoderma* spp. are to be effective in controlling *P. weirii*. Effective biological control agents that are antagonistic to *P. weirii* must colonize infested major roots and displace the pathogen within them in 5-10 years. Beyond that time, newly established seedlings will have become infested and their interconnecting root systems will enable the disease to spread and perpetuate (Nelson and Thies 1985).

Bacillus

In 1980, results from an *in vitro* study were reported in which an antibiotic formed by an unnamed *Bacillus* sp. isolated from the soil in a red alder stand inhibited the growth of *P. weirii*, *H. annosus*, *A. mellea* and *Phythophthora cinnamomi* Rands (Hutchins 1980). Antagonism was tested using the cross-streak method on malt-yeast-peptone (MYP) agar in petri dishes. A plug or disk of the test organism was placed on the agar opposite a streak of bacteria. The plates were later inspected for a clear zone indicative of inhibition of growth of the test fungus and by the bacterium (Hutchins 1980).

Heat stability and antibiotic persistence in the medium were also tested using a modified cellophane membrane technique. Squares of autoclaved cellophane, dialysis membrane were inoculated with a broth containing the agar and the bacterium, and then placed over the petri dishes containing the growth medium in which the test fungus grew. The semi-permeable barrier provided by the cellophane membrane eliminated direct contact between the fungus and the bacterium, but permitted diffusion of the bacterial antibiotic into the fungal medium. The antibiotic effect lasted up to two months even after heat treatments to 121°C.

Although these reports are promising, no further results from either laboratory or field studies have been published.

Streptomyces and non-filamentous bacteria

In 1981, another *in vitro* study (Hutchins and Li 1981) reported antagonism to *P. weirii* from microbial isolates from soil associated with both conifers and red alder. Using a double-layer plate technique developed by Li et al. (1969) to test for antagonism, Hutchins and Li (1981) found that conifer soil supported higher populations of antagonistic *Streptomyces* spp. than alder soil (27% of isolates from conifer soil were antagonistic to *P. weirii* as compared to 14% for alder soil). Populations of non-filamentous bacteria were low in both soils; however, a higher percentage of those found in the alder soil were antagonistic (21% for alder soil compared to 4% for conifer soil). Season of sampling also seemed to affect the percentage of isolates that were found to be antagonistic. For example, October samples of *Streptomyces* yielded the highest percentage (48%) of isolates antagonistic to *P. weirii*).

No mention of potential for biocontrol was mentioned in the study, and no further report has been published to date with regard to biocontrol of *P. weirii* using *Streptomyces* or non-filamentous bacteria.

Future Prospects

More research is needed to identify and develop effective biocontrol agents for P. weirii. Operationally, in order to supplant a pathogen such as P. weirii, a shift in environment is required to suppress its metabolism (Baker and Cook 1974). To date, no one biological agent or combination of agents has proven effective in creating this shift. Consequently, biocontrol agents are not competing at a level that will result in the control desired. Some other tactic may be needed in combination with the use of biological agents. Such an integrated approach might cause sufficient environmental changes to suppress the pathogen or may allow environmental change to synergise with another form of control.

CHEMICAL CONTROL

Research into the possible chemical control of P. weirii in Douglas-fir has centered around the use of nitrogenous fertilizers, phenolic compounds, fumigants, and most recently glyphosate. While none of the above is currently being used operationally, some of the fumigants have potential, at least on a small scale.

Nitrogenous Fertilizers

Research up to the late 1970's with additions of nitrogen to soils to control P. weirii has been reviewed by Ward (1979). Two researchers who worked independently, E.E. Nelson from the Pacific Northwest Forest and Range Experiment Station, U.S.D.A. Forest Service and G.W. Wallis from the Pacific Forestry Centre, Forestry Canada, are responsible for most of the published literature. Their hypothesis was that an increase in available nitrogen would stimulate the growth of other microorganisms, like Trichoderma spp., that are antagonistic to P. weirii. Nelson (1970) reported that in laboratory tests nitrogen applied as either ammonium chloride or ammonium nitrate dramatically reduced the viability of P. weirii in buried wood cubes. In field tests, the application of urea to forest soil containing P. weirii-infested wood cubes resulted in markedly reduced survival of the fungus (Nelson 1975). The reduction was correlated with increased populations of the antagonistic Trichoderma spp. (Nelson 1976).

Wallis and Reynolds (1974) reported conflicting results from a field trial in which nitrogen was applied at rates as high as 2,240 kg per ha to a Douglas-fir stand with well established P. weirii centres. While there was increased vigor in surviving trees in the treated plots, there was no change in the mycelial spread of the pathogen one year after treatment. A further assessment two years after treatment resulted in continuing tree mortality and vigorous fungal growth in both the control and treated plots (Wallis 1976).

While P. weirii might be eliminated from wood material by making the environment more favorable for antagonistic fungi, it appears from the above results that the addition of fertilizer will have little or no effect when the pathogen is well established and protected within the stump and roots of infected trees.

Since the retirement of G.W. Wallis, only E.E. Nelson is conducting research with nitrogenous additions to soil in attempts to control P. weirii. In a 1976 trial, nitrogen in the form of ammonium nitrate or urea was applied to stumped and non-stumped clearcuts to encourage soil borne organisms, like Trichoderma, to invade roots and displace P. weirii. While eight year results show that both bulldozing and fertilizing have increased seedling height and diameter at breast height, the efficacy of the treatments on laminated root rot cannot be assessed yet (Thies and Nelson 1988).

Phenolics

Research on the effects of phenolic compounds produced by red alder and Douglas-fir on P. weirii began in the late 1960's (Ward 1979). All of the work reported was done by researchers at Oregon State University and the Pacific Northwest Forest and Range Experiment Station, U.S.D.A. Forest Service. While some 25 different compounds were tested by in vitro studies, only three compounds, vanillic, syringic, and ferulic acid (all produced by Douglas-fir) were found to be somewhat inhibitory to P. weirii. None of the three was deemed to have potential as an effective control agent.

Fumigants

Fumigants were shown to be effective in eradicating pathogenic fungi from infested wood buried in soil as early as 1936 (Godfrey 1936). However, no attempts were made to test the effectiveness of soil fumigants on P. weirii-infested wood until the mid 1970's (Thies 1984). Five fumigants, carbon disulfide, chloropicrin, methyl bromide, Vapam, and Vorlex (20% methylisothiocyanate, 80% chlorinated C_3 hydrocarbons, V/V) were tested and shown to be effective in eliminating P. weirii from 5 cm cubes of wood buried in soil.

Following up on these results, Thies and Nelson (1982) began a series of experiments designed to test whether soil fumigants could be used to eradicate P. weirii from infested roots and stumps. In their first experiment, chloropicrin, allyl alcohol, Vapam, and Vorlex were applied in the spring of 1978 to stumps of Douglas-fir trees cut in the fall of 1977. Stumps ranging in diameter from 23 to 72 cm with stain or advanced decay were tested. Each stump received 1,000 ml of active ingredient of one of the test chemicals applied to 40 cm deep holes drilled into the stump. The holes were then plugged with dowels and the top of the stump was covered with fiberglass cloth and asphalt roofing compound.

One year after treatment, stumps were bulldozed from the soil and disks were cut from the stump and roots at regular intervals. Disks were split, and chips taken from the split face were placed in incubation tubes filled with malt agar and incubated for 14 days at room temperature. Presence of P. weirii was determined from the morphological features of developing cultures (Thies and Nelson 1982). All of the fumigants eliminated P. weirii from the stumps and 92% of all infected roots. Over half of the disks which yielded viable P. weirii were from root systems from dead trees which had partially deteriorated sapwood. Possibly, this sapwood allowed the fumigant to diffuse out of the stump before it adequately penetrated into the root system. Vapam-treated stumps yielded the highest percentage of disks with viable P. weirii. Vorlex-treated stumps yielded the fewest disks with viable P. weirii followed closely by chloropicrin-treated stumps.

The effectiveness of the fumigant appeared to be related to stump size. _P_. _weirii_ was recovered from half of the stumps over 48 cm. in diameter but from none <48 cm. in diameter. This disparity suggests that the dosage of 1,000 ml was less than the minimum effective dosage for large stumps (Thies and Nelson 1982).

No attempt was made to define the maximum effective distance for each fumigant; however, _P_. _weirii_ could not be recovered from root disks with advanced decay taken 2.8 m from one chloropicrin treated stump. Likewise, the minimum root size penetrated by each fumigant was not determined; however, it was established that all of the fumigants tested diffused through root systems in concentrations high enough to eliminate _P_. _weirii_ in roots as small as 2 cm in diameter. Roots smaller than 2 cm were thought to be of little consequence as a source of inoculum, as they would decompose rapidly after the tree was cut (Thies and Nelson 1982).

Based on these findings, a second set of experiments was initiated to test several application rates and techniques to eradicate _P_. _weirii_ from Douglas-fir stumps and roots (Thies and Nelson 1987a). Because of their effectiveness in the earlier work, chloropicrin and Vorlex were selected as the study fumigants. Both are widely used in agriculture, and are strong lacrimators that are easily detected at low concentrations.

Methylisothiocyanate (MIT) which is an active ingredient in Vorlex and is also shown to move through wood blocks and kill _P_. _weirii_, was also to be tested. MIT was thought to have an advantage over both Vorlex and chloropicrin in that it forms a white, waxy solid at room temperature, making it easier to handle in the field than a liquid. Dosage was based on stump and root biomass, estimated from stump diameter. A standard dosage (D) was 6.7 ml per kilogram of treated biomass for both chloropicrin and Vorlex and 1.5 g per kilogram of treated biomass for MIT. The dosage for MIT was based on the concentration of MIT in Vorlex (232g MIT per 1.0 litre Vorlex). Chloropicrin and Vorlex were also tested at dosages of 0.5 D and 1.5 D (Thies and Nelson 1987a).

Holes were drilled in the stump top to a depth slightly below the soil line with at least one hole in each quadrant. An equal portion of the liquid fumigant was poured into each hole and plugged with a dowel. MIT was applied in either open glass tubes or gelatin capsules over which water was poured to dissolve the capsules. All holes were plugged with dowels.

Both live-tree stumps (trees felled the previous fall) and dead-tree stumps were treated. Only chloropicrin was applied to dead-tree stumps.

Stumps receiving chloropicrin and Vorlex were further divided into two categories: sealed with asphalt roofing compound and non-sealed. Both fiberglass cloth and roofing compound were used to seal stumps with advanced decay. All MIT-treated stumps were sealed; some were also covered with plastic (Thies & Nelson 1987a).

Two years after treatment, all stumps were removed from the soil using a large backhoe. Sample roots were taken from each stump and cleaned and examined at 30 cm intervals for presence of fungicide and viable _P. weirii_. Increment cores from treated roots were placed in glass tubes containing a growing colony of P. weirii on malt agar. A core sample was noted positive for a fungitoxic level of fumigant only if there was no growth in the P. weirii colony after 5 days incubation (Thies and Nelson 1987a).

Disks from roots were analyzed for the presence of P. weirii by isolating the fungus from sample chips as in the earlier experiment (Thies and Nelson 1982), and by incubating the disks themselves within loosely-tied plastic bags stored at ambient temperature for 4 to 8 weeks (Thies and Nelson 1987a).

Of the 844 disks recovered from fumigant treated stumps, 221 (26%) were P. weirii positive; 99% were confirmed by the isolation method, whereas only 33% were confirmed by incubation. Thies and Nelson (1987a) interpreted this to mean that the fungus or the wood substrate had been altered so that the fungus was less vigorous and was unable to grow out of the disk to form a felt. If this were true, the amount of effective residual inoculum would be significantly lower than 26%.

There were no significant differences between the results for the nine liquid fumigant treatments. The pooled data for these treatments revealed that the residual inoculum volume, as determined by presence of viable P. weirii, was 22% of the prefumigation volume. If the residual inoculum only included root segments in which the fungus had the ability to grow onto the surface of the sample disk, then the residual inoculum volume was only 7% of the prefumigation volume. MIT treatments were not as effective as the liquid-fumigant treatments and resulted in a rapid increase in the percentage of residual inoculum volume with distance from the stump (Thies and Nelson 1987a).

Two stumps and root systems from each treatment, including the untreated controls, were bioassayed for presence of fumigants. Cores were collected from 391 sample locations on roots and 55 sample locations on stumps. Most samples collected from treated stumps were biomass positive (i.e. no growth). Of the 44 roots biossayed from fumigant-treated live-tree stumps, only 13 had no positive responses; while another 25 had some positive responses. In each instance of biomass-positive response, core samples were part of an unbroken sequence from stumps of biomass-positive samples. Comparison of the biomass data with other data from the study did not reveal a pattern of residual fumigant related to stump size, fumigant, fumigant dose, or sealing (Thies and Nelson 1987a).

Thies and Nelson (1987a) also reported that the asphalt seal on fumigated stumps or the covering of treated, dead-tree stumps with plastic did not further reduce the amount of residual inoculum. Finally, in the earlier study it had been suggested that decayed wood might promote the loss of fumigants; however, in the subsequent study, there was no relationship between degree of decay and ability of the fumigants to kill P. weirii.

Also, in 1982, W.G. Thies and E.E. Nelson began to investigate fumigant injection in live Douglas-fir as a therapeutic treatment for P. weirii infection. Three fumigants, chloropicrin, MIT, and Vorlex were tested on trees in three infection classes: 1) infected, 2) probably infected (crown symptoms and inoculum found on one or more trees within 5 m, but P. weirii not found on subject tree, and 3) probably uninfected, (no symptoms and no identified inoculum source within 25 m of subject tree). The same standard doses for chloropicrin, Vorlex and MIT were used as in the previously described study.

Chloropicrin was also tested at 1 D, 0.5 D, 0.25 D, and 0.125 D. MIT was tested at 1 D, 0.5 D and 0.25 D. Vorlex was tested only at 0.5 D (Thies and Nelson 1987b). Seven of the nine treatments were applied in March 1982; Chloropicrin 0.125 D and Vorlex 0.5 D were applied in April 1983.

At 5, 18 and 30 months following the first treatments the crown of each tree was photographed and rated on an 11-point scale. Trees which died were felled and the stumps were excavated. Roots were sampled and tested for presence of viable P. weirii as above.

Of the 120 trees treated, 95 (73%) were still alive after three growing seasons (30 months). Of 25 treated trees that died, 24 were treated with 0.125 D chloropicrin. In contrast, the crown condition of MIT-treated trees did not appear different from the control trees.

Analysis of the roots of killed trees confirmed that fumigants can reduce P. weirii infection. Only 22% of root disks from the 25 chloropicrin or Vorlex-treated trees contained viable P. weirii; however, a comparison of treatment effectiveness cannot be made until all study trees are felled and their roots examined (Thies and Nelson 1987b). The fact that MIT has resulted in the least amount of mortality to date, may not make it the best fumigant for maintaining or improving tree health in live trees based on its relative lack of efficacy in the treated stump experiments.

W.J. Bloomberg, the Pacific Forestry Centre, Forestry Canada, has tested one additional fumigant, Basamid. In 1982 and 1983 Basamid was applied to both infected stumps and standing infected trees near Lake Cowichan. The fumigant was poured at a rate of 1 g of chemical per kg of stump mass into holes drilled into the base of the stump. Basamid has little or no effect on the growth of P. weirii in the roots of treated stumps and trees (G. Reynolds,[*] pers. comm.).

Glyphosate

Glyphosate is a broad spectrum herbicide which is translocated readily in vascular tissues to physiological sinks (Grossland and Atkinson 1985). Applications made late in the growing season are translocated directly to the roots (Grossland and Atkinson 1985). The mechanism of action of glyphosate is its ability to inhibit the formation of phenylalanine, an essential amino acid, which results in metabolic failure and death (Grossland and Atkinson 1985).

In recent years some attention has been given to the possible control of P. weirii using the herbicide glyphosate. I have observed that fungal activity and decomposition have been enhanced in above-ground portions of deciduous and coniferous trees treated with glyphosate. These observations are consistent with the hypothesis that glyphosate-treated trees are unable to defend themselves against decay fungi. If the same phenomenon were to occur in roots of Douglas-fir, glyphosate could be used to reduce inoculum in infested roots by

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creating a more favorable substrate for invasion by soil microorganisms which could displace *P. weirii*. The herbicide itself might even kill the fungus. Quilty and Geoghegan (1975) reported that radial growth of several fungi was significantly reduced when the glyphosate formulation, Roundup, was incorporated into the growth media. Two other characteristics make glyphosate an excellent candidate as a control for *P. weirii*: 1) it translocates readily in plant tissue and thus has systemic activity, and 2) it has relatively low toxicity to vertebrates, which makes it safe for workers during application (Grossland and Atkinson 1985).

In 1986, Canadian Pacific Forest Products Limited initiated a field trial to test glyphosate as a pre-logging treatment to eliminate or at least control the spread of the disease after logging and planting. The trial included three separate studies each designed to look at a specific objective. The objectives were: 1) to quantify glyphosate translocation into the roots of healthy and infected Douglas-fir using High Performance Liquid Chromatography; 2) to compare fungal activity and root decomposition in treated and control roots by comparing oven-dried root sample weights, and 3) to assess the effects, if any, of glyphosate on the growth of mycelium on treated roots by microscopically examining root samples.[7]

Fifty two healthy and fifty infected trees were selected over a 4

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[7] Fraser, R.G. 1987. Field evaluation of glyphosate as a prophylactic and/or eradicant treatment for the control of *Phellinus weirii* in second growth Douglas-fir. Canadian Pacific Forest Products Limited. Unpubl. Report.

ha site. Healthy and infected trees were then randomly assigned to one of the three studies.

Glyphosate was applied to a continuous frill cut into the phloem of Douglas-fir trees (mean dbh 33 cm) at one of two rates. These rates represented normal and double the amount of glyphosate in the recommended rate for chemical thinning using Roundup (Monsanto undated).

Root samples from treated trees were to be taken one month after treatment for residue analysis using gas liquid chromotography. However, after a sub sample taken 23 days after treatment was found to have no detectable residues, the sampling methodology was modified. Post-treatment samples (18 in total) were taken at 23 days, 37 days, 3 months and 5 months from 7 of the treated trees. Of the 18 samples, 8 were from roots, 4 were from the base of stumps and 6 were taken near the frill. Only 8 of the 18 samples (1 sample from a root, 1 from a stump and 6 from the frill area) had a detectable amount of glyphosate (limit of detection was > 1 ppm). Since the translocation into the roots appeared to be poor and the levels detected varied greatly, the trial was abandoned.[7]

The hypothesis that glyphosate can be used to control P. weirii still warrants investigation despite the failure of the initial attempt. Some recommendations for future work which stemmed from the initial trial are: 1) glyphosate should be tested initially on smaller trees, 2) higher doses, possibly five or ten times the recommended rate for chemical thinning using Roundup, should be tested, and 3) a method other than hack and squirt, possibly the drill and plug method, should be used to administer the herbicide. In addition, late summer early fall, may not be the optimal time to administer the treatment. There is some evidence (J.D. Beale,[a] pers. comm.) that application made to the cut surface of a stump immediately after felling during the active growing season may enhance the movement of the herbicide into the root system, as the severed translocation stream retreats into the roots.

Prognosis

In summary, the prospects for operational chemical control, particularly with fumigants, appears to be good. More research is needed however to develop application methods which are both safe and inexpensive. Preliminary efficacy results for chloropicrin suggest that this fumigant could be used operationally on a small scale to protect individual trees or groups of trees from P. weirii in areas such as parks. More research is required to determine if glyphosate can be used as a control for P. weirii.

If chemical controls can be developed for use on a large scale the cost per ha should be considerably less than stumping. In addition, chemical control can be used on steep slopes.

Containment

Managing a site to contain the spread of the disease would most likely be a strategy implemented in an existing stand. Selectively removing susceptible Douglas-fir during pre-commercial thinning

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[a] Forest Pathologist, Vancouver Forest Region, B.C. Forest Service, Burnaby, B.C.

(=spacing) can reduce root contacts from disease centres into healthy trees. Tolerant, resistant and immune tree species would not have to be cut if they were next to affected trees. Stocking density will influence the number of nonsymptomatic trees that have to be cut to break the disease pathway to healthy trees (Hadfield et al. 1986). In most sapling stands, non-symptomatic trees would have to be cut within a zone that extends two normal tree spacings beyond trees that have sparse, yellow foliage (Hadfield et al. 1986).

In sapling stands where small centres of dead and dying trees are common (>10 per ha), pre-commercial thinning should not be done as many of the leave trees, while not showing symptoms of infection at the time of spacing, are infected and will die before the stand is harvested (Wallis 1976). These stands should be left until they are ready for commercial thinning. At this time disease symptoms will be more advanced and an accurate appraisal of disease intensity will be possible. During the commercial thinning many of the windthrown, root-rotted trees and standing dead trees can be recovered in addition to healthy trees cut in the path of the disease which will prevent further spread (Wallis 1976).

Managing as if the Disease Were not Present

Managing as if the disease were not present should not be considered, particularly on medium to good sites where productivity losses are greatest (Wallis 1976). van der Kamp et al. (1986) estimated that all infected coastal Douglas-fir stands 40 to 80 years old are at least 10-15% less productive when compared to healthy stands. By the year 2000 the deficiency could be 20% and entail an annual loss in stumpage revenue of $10,000,000 (van der Kamp et al. 1986). Thies (1984) estimates that after two or three rotations, in the absence of any successful intervention to control laminated root rot, losses in Douglas-fir stands can be expected to be 50 to 90 percent of the predicted volume.

A decade ago the treatment of stands infected with _P_. _weirii_ in B.C. was infrequent (J.A. Muir,[9] pers. comm.). However in recent years an increased awareness of pest damage by forest land managers, the onset of timber shortages, and new legislation making treatment of pests mandatory on crown land has meant that the do-nothing option is exercised less frequently. A similar situation has developed in Washington State and in other parts of the U.S.A. (K. Russell,[10] pers. comm.).

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RECOMMENDATIONS FOR FURTHER RESEARCH

While the understanding of P. weirii in Douglas-fir forests has increased greatly in the past 40 years, there are still many questions which remain unanswered. One might question why the answers to these questions have been so slow in coming. Thies (1984) identifies some of the problems associated with P. weirii research. Since P. weirii is a root pathogen, excavation is required to study interactions between roots, soil and microbial pathogens. However, by excavating roots from the soil the scientist often destroys the very things he is trying to observe. Another problem is related to the host's longevity. Over a rotation, trees change in response to disease, environmental stresses, competition for growing space, or silvicultural manipulation. Long-term studies are required to track the disease over the course of a rotation under various stand conditions. Such studies are subject to many variables, such as staff turnover, changes in researchers' and administrators' priorities and policies, as well as the silvicultural prescription chosen by the forest manager. Over the span of a long-term study, research administrators may revise priorities or shift financial support to newly-emerging problems. The presence of research plots may force forest managers to alter management or may require extra work by his field staff. Finally, long-term field plots are subject to natural hazards such as fire, storms, geologic events and the depredations of wildlife.

It can be argued that forest managers currently have damage appraisal techniques and control methods available to adequately manage

P. weirii, however, further research will lead to an increase in the level of control achieved. There is a need to continue studies on the relationship between P. weirii incidence and its occurrence in and spread to different ecosystems. Once this work is completed, a hazard rating system for operational use can be developed.

More effort is needed to identify Douglas-fir trees which are resistant to P. weirii. Once identified, the mechanisms conferring the resistance need to be researched. One of the spin-offs of this work would be the development of a reliable screening technique for testing seed orchard trees. Long term productivity plots are needed in areas planted with mixtures of Douglas-fir with less susceptible or resistant species. Disease spread under different stocking densities of susceptible hosts needs to be evaluated.

Different species and strains of Trichoderma and other antagonistic microorganisms need to be identified and tested for P. weirii control. Bacillus, Streptomyces and non-filamentous bacteria appear to be antagonistic in in vitro studies; in vivo studies are now required.

Fumigants hold promise for P. weirii control. However, cost-effective and safe treatments need to be developed before fumigants can be used operationally. Glyphosate requires further testing as a prophylactic and/or eradicant for P. weirii.

Cost effective techniques for mechanical control are needed. One method which holds promise is timber pushing with large bulldozers. Both infected and non-infected trees are pushed over and piled for extraction with skidders or cable systems. By pushing over infected trees, inoculum and potential substrate would be removed from the soil during the harvesting phase.

Better damage appraisal techniques are required. Advances in computer technology will be keys to the development of these techniques. Disease impact models incorporating up-to-date data on damage need to be refined to mimic closely what happens naturally. These models should then be applied to improve pest management decision making, possibly through the development of artificial intelligence systems.

Many of these topics are currently being studied and the understanding of *P. weirii* in Douglas-fir forests is increasing rapidly. The future looks bright for *P. weirii* control, provided that those responsible for forest management continue to invest the needed money to manage it effectively.

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