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Laminated Root Rot in Western North America

Walter G. Thies and Rona N. Sturrock



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Laminated Root Rot in Western North America

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Abstract

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Laminated root rot, caused by *Phellinus weirii* (Murr.) Gilb., is a serious root disease affecting Douglas-fir and other commercially important species of conifers in northwestern North America. This report gives an overview of the disease as it occurs in the Pacific Northwest in Canada and the United States. Information on recognizing crown symptoms and signs of the disease is presented. The disease cycle of laminated root rot, from initiation to intensification and distribution within infected stands, is described. Finally, disease management strategies during stand development and at stand regeneration are discussed. Features on the nomenclature of the fungus and on its management by silvicultural and mechanical approaches also are included. The report is intended as a general reference for a wide audience.

Keywords: *Inonotus sulphurascens*, laminated root rot, *Phellinus sulphurascens*, *Phellinus weirii*, *Poria weirii*, root diseases.

Preface

The information presented here has been compiled from many sources and represents both published research findings and observations of forest pathologists and resource managers in the Pacific Northwest in Canada and the United States. Some of the management recommendations are based on research still in progress. Although much of the information focuses on high volume coastal stands, it can be generally applied to both coastal and inland (east of the crest of the Cascade Range) stands. This report is intended as a general reference for a wide audience including laypersons, resource managers, students, and members of the research community. Although many primary references are listed, a complete literature review or listing of all publications on laminated root rot is beyond the scope of this presentation.

This report updates information in earlier publications intended to provide a guide to resource managers: Hadfield 1985, Hadfield and others 1986, Morrison and others 1992, Thies 1984, and Wallis 1976. These earlier publications are recommended as sources for additional color illustrations to augment those shown here.

Table 1—Susceptibility of western North American tree species to laminated root rot

Level of susceptibility ^a and species	Scientific name
Highly susceptible:	
Douglas-fir	<i>Pseudotsuga menziesii</i> (Mirb.) Franco
Grand fir	<i>Abies grandis</i> (Dougl. ex D. Don) Lindl.
Mountain hemlock	<i>Tsuga mertensiana</i> (Bong.) Carr.
Pacific silver fir	<i>Abies amabilis</i> Dougl. ex Forbes
White fir	<i>Abies concolor</i> (Gord. & Glend.) Lindl. ex Hildebr.
Intermediately susceptible:	
California red fir	<i>Abies magnifica</i> A. Murr.
Engelmann spruce	<i>Picea engelmannii</i> Parry ex Engelm.
Giant sequoia	<i>Sequoiadendron giganteum</i> (Lindl.) Buchholz
Noble fir	<i>Abies procera</i> Rehd.
Pacific yew	<i>Taxus brevifolia</i> Nutt.
Sitka spruce	<i>Picea sitchensis</i> (Bong.) Carr.
Subalpine fir	<i>Abies lasiocarpa</i> (Hook.) Nutt.
Western hemlock	<i>Tsuga heterophylla</i> (Raf.) Sarg.
Western larch	<i>Larix occidentalis</i> Nutt.
Tolerant:	
Lodgepole pine	<i>Pinus contorta</i> Dougl. ex Loud.
Sugar pine	<i>Pinus lambertiana</i> Dougl.
Western white pine	<i>Pinus monticola</i> Dougl. ex D. Don
Resistant:	
Alaska-cedar	<i>Chamaecyparis nootkatensis</i> (D. Don) Spach
Incense-cedar	<i>Libocedrus decurrens</i> Torr.
Ponderosa pine	<i>Pinus ponderosa</i> Dougl. ex Laws.
Port-Orford-cedar	<i>Chamaecyparis lawsoniana</i> (A. Murr.) Parl.
Redwood	<i>Sequoia sempervirens</i> (D. Don) Endl.
Western redcedar	<i>Thuja plicata</i> Donn ex D. Don
Immune:	
Hardwoods^b—	
Bigleaf maple	<i>Acer macrophyllum</i> Pursh.
Mallow ninebark	<i>Physocarpus malvaceus</i> (Greene) Kuntze
Ocean-spray	<i>Holodiscus discolor</i> (Pursh) Maxim.
Red alder	<i>Alnus rubra</i> Bong.
Rocky Mountain maple	<i>Acer glabrum</i> Torr.
Vine maple	<i>Acer circinatum</i> Pursh

^aLevels of susceptibility: high—readily infected and readily killed; intermediate—readily infected, usually not killed, often develops butt decay; tolerant—infrequently infected unless growing in association with the most susceptible species, rarely killed; and resistant—rarely infected, almost never killed.

^bAll hardwoods are immune.

Sources: Adapted from Filip and Schmitt 1979, Hadfield 1985, Nelson and Sturrock 1993, Wallis 1976.

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Introduction

Laminated root rot, caused by the fungus *Phellinus weirii* (Murr.) Gilb., is widespread in southern British Columbia, Washington, Oregon, northern California, western Montana, and northern Idaho (fig. 1). There are two fairly distinct forms of the fungus. One form is a common cause of butt rot in western redcedar¹ in the northern Rocky Mountains of the United States and the interior of British Columbia. The other commonly kills Douglas-fir, and several other conifer species, throughout northwestern North America but does not cause extensive mortality in western redcedar (see "What's In a Name" p. 4). In this paper we focus on the form common on Douglas-fir.

Phellinus weirii, like many other tree root pathogens, is believed to have coevolved with its hosts and thus is a natural, and perhaps even necessary, part of many forest ecosystems. This pathogen, however, does not destroy entire stands over large areas or threaten the

existence of any host species. Whether the effects of *P. weirii* in an infested stand are considered beneficial or detrimental depends on the management objectives for the site. A Douglas-fir stand heavily impacted by laminated root rot may be viewed in one setting as undesirable because of damage to facilities from diseased trees knocked down by wind (windthrow) or because of significant reduction in anticipated timber volume. In another setting, with different management objectives, loss of trees as a result of disease processes may be desirable because the laminated root rot-caused openings, scattered mortality (lower density stand), and increased volume of large woody debris may provide big game forage, small animal habitat, sources for alternate forest products, increased diversity in the plant community, and enhanced visual quality on a landscape scale.

¹Scientific names for all tree species are given in table 1, page iii.

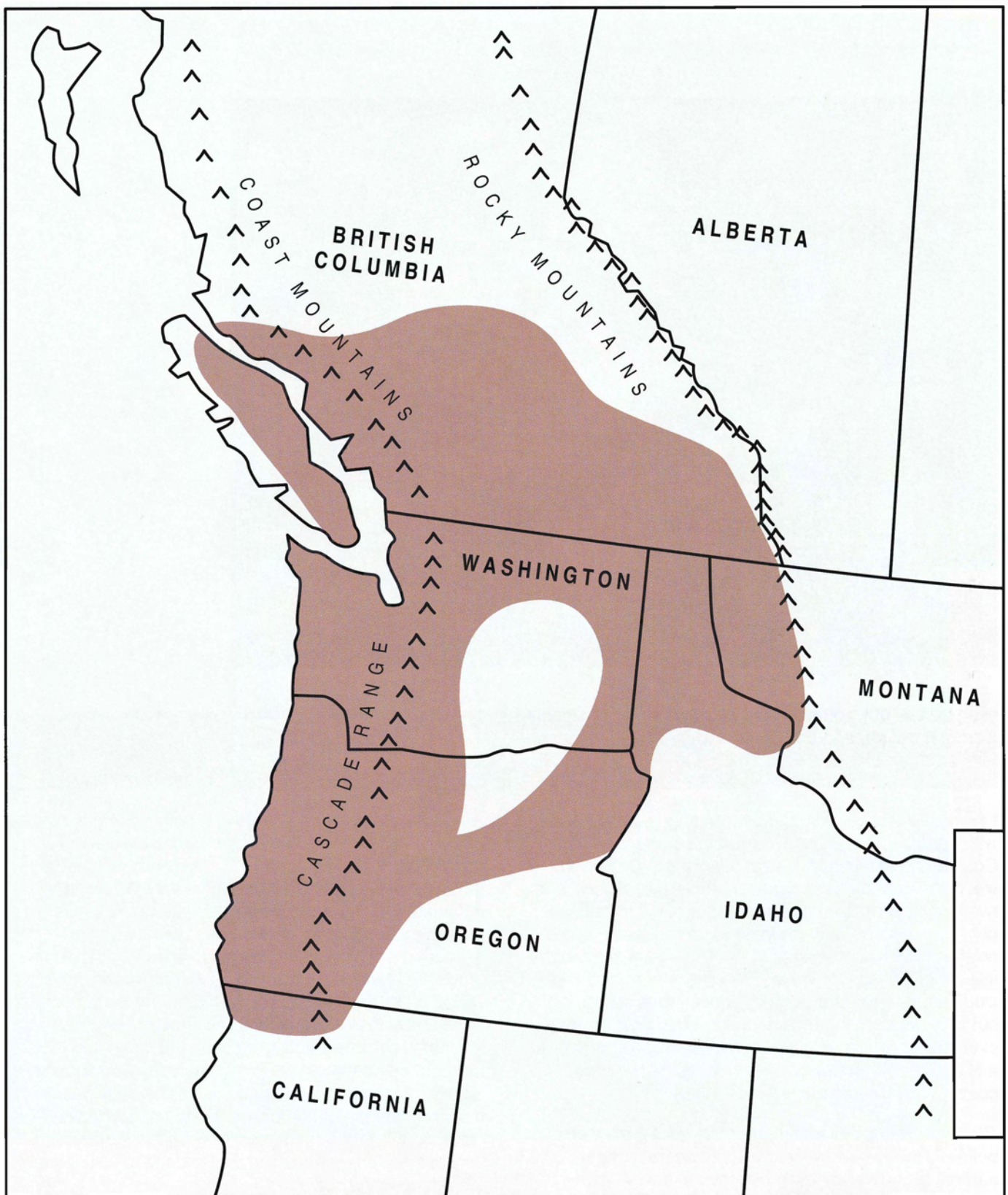


Figure 1—Distribution of laminated root rot in Western North America.

Douglas-fir is the most economically important host of *P. weirii*, but most conifer species are susceptible to some degree (table 1). Laminated root rot is estimated to reduce timber production by about 4.4 million cubic meters (157 million cubic feet) annually (Nelson and others 1981). Although timber volume losses to *P. weirii* are most conspicuous as mortality or windthrow, tree growth also may be reduced for several years before death (Bloomberg and Reynolds 1985, Thies 1983). It has been estimated that laminated root rot occurs on 8 percent² of the commercial forest land in Washington and Oregon and causes a 40- to 70-percent reduction in wood volume on the areas affected (Goheen and Hansen 1993). The effects of laminated root rot are variable, but generally stand density and timber production fall below those of uninfected stands. Substantial reductions in timber volume and growth have been demonstrated in some second-growth Douglas-fir stands (Bloomberg and Reynolds 1985; Bloomberg and Wallis 1979; Buckland and others 1954; Lawson and others 1983; Mounce and others 1940; Thies 1982, 1983).

Reduced volume of preferred timber species due to disease mortality or growth loss may be partially offset by regeneration of less susceptible species in the created openings or by the increased growth of adjacent susceptible, but uninfected, residual trees (Oren and others 1985).

Regardless of its effects, laminated root rot is a significant natural force to be considered by resource managers, whether planning for individual stands or entire ecosystems. Society today demands an increasingly broad range of forest products and experiences, including an ever-increasing volume of fiber from a continually shrinking base of commercial forest land. Understanding and properly managing laminated root rot is imperative to achieving desired management objectives.

²Personal communication, Don Goheen, U.S. Department of Agriculture, Pacific Northwest Region, Forest Pest Management, Medford, OR.

What's In a Name?

Past and Present

The current commonly accepted scientific name of the fungus causing laminated root rot is *Phellinus weirii*. A thorough taxonomic review of this fungus goes well beyond the scope of this paper but is available elsewhere (Larsen and others 1994); however, a summary of the past names and possible future changes may be helpful.

In 1914, a fungus, *Poria weirii* Murrill, was described as occurring on western redcedar in northern Idaho (Murrill 1914). Subsequently, the host range was extended to *Pseudotsuga menziesii*, *Abies* spp., *Picea* spp., and *Tsuga* spp. (Bier and Buckland 1947). Yellow laminated root rot became the common name of the disease caused by this fungus.

It became generally accepted that two recognizable forms of *Phellinus weirii* existed: a redcedar form and a Douglas-fir form. Between 1930 and 1960, numerous researchers noted differences between the two forms but concluded that the fungus on Douglas-fir (and other conifers) was the same as that on redcedar. Others designated isolates from Douglas-fir as "annual *Poria weirii*" and those from redcedar as "perennial *Poria weirii*", or determined that "cedar isolates" and "noncedar isolates" could be separated on the basis of agar culture characteristics. Differences also were noted in the type of disease caused by these two forms: the Douglas-fir form killed trees as a root disease and the redcedar form generally was confined to the heartwood of trees and was not a tree killer.

In 1974, based on characteristics of the fruiting body, both forms of the fungus were included in the new name *Phellinus weirii* (Gilbertson 1974). By 1976, *Phellinus weirii* had become the accepted name of the pathogen, and the disease it caused was commonly known as laminated root rot.

Future

Based on pairing studies and studies using molecular and serological techniques, it is proposed that isolates of *Phellinus weirii* from redcedar and Douglas-fir are different species or, at the very least, represent different intersterility groups (Angwin 1989). Further, similar techniques have been used to show that isolates of *Phellinus sulphurascens* Pilat described from Russia in 1936 and the North American Douglas-fir isolate of *Phellinus weirii* are similar; the *Phellinus sulphurascens* isolate from Russia and the North American redcedar isolate are clearly different. The oldest name for the pathogen causing laminated root rot on Douglas-fir is considered to be *Phellinus sulphurascens*. It is proposed that the pathogen isolated from redcedar be called *Phellinus weirii* (Ryvarden and Gilbertson 1994).

Further complicating the nomenclature of these two species is the fact that new combinations for both in the genus *Inonotus* have been proposed (Kotlaba and Pouzar 1970, Larsen and others 1994). *Inonotus* is separated from *Phellinus* based on microscopic details of conk construction. A new combination has been proposed that would result in the pathogen causing laminated root rot on Douglas-fir being called *Inonotus sulphurascens* (Pilat) Larsen et al. (Larsen and others 1994).

Although there is general agreement among North American forest pathologists that the redcedar form and the Douglas-fir form of the pathogen are different species, there is not yet unanimity on the proper names. Until a stable phylogenetic system of genera in the Hymenochaetaceae is developed, presented, debated, and supported by forest pathologists in general, it will be less confusing to continue use of the name *Phellinus weirii* for the fungus that causes laminated root rot of Douglas-fir.



Symptoms and Diagnosis

Appearance of Disease Centers

Laminated root rot frequently is first detected during ground reconnaissance and surveys when canopy openings and standing dead (figs. 2 and 3) and fallen (fig. 4) trees are observed. Fallen trees in disease centers tend to occur in a random pattern of crossed stems or leaning trees—unlike storm blowdown, where the trees usually fall in one direction, all at about the same time. When a tree uproots, extensively decayed major roots typically break off close to the root collar and only short stubs remain attached to the tree (fig. 4). The root collar, root stubs, and attached soil is called a “root wad” or “root ball.” These root wads, which may resemble a closed fist, are characteristic of laminated root rot. Some hosts with advanced decay in the lower bole, frequently grand fir in inland stands and mountain hemlock in high-elevation stands in the Cascade Range, can break off (fig. 5). Douglas-firs break above the root collar rarely in coastal stands, occasionally in stands on the western slope of the Cascade Range, and frequently in inland stands. Callus tissue (fig. 6), which forms as a result of wounding or infection, may

develop at ends of broken roots or roots that have decayed. Adventitious roots developing from or near this callus are thought to functionally replace roots killed by the disease and thus prolong the lives of some infected trees.

In stands where mature Douglas-fir are predominant, disease centers may range from a few trees to most of the trees on a hectare (2.5 acres) and occasionally to larger areas. Centers in mountain hemlock stands in the Cascade Range have been estimated to cover up to 10 hectares (25 acres). Standing dead or symptomatic live trees typically are present around the edges of infection centers and scattered within them. Seedlings of susceptible species that become established in centers often become infected and die at a young age, while tolerant conifers often continue to grow. In coastal Oregon, Washington, and British Columbia, large patches of bigleaf maple, vine maple, red alder, and other hardwoods often develop in disease centers.

Figure 2—Laminated root rot infection centers cause openings in stands. These openings characteristically have dead or declining host trees at their margins.



Figure 3—Large laminated root rot infection centers may be occupied by tolerant conifers, shrub species, and hardwoods.





Figure 4—Uprooted Douglas-firs with root wads characteristic of laminated root rot infection. Decayed roots have broken close to the root collar leaving only stubs.



Figure 5—A *Phellinus weirii*-infected grand fir that has been broken off at stump height. Note characteristic laminated decay.

Western redcedar replacement is common in the Puget Sound Basin.

In parts of the Idaho Panhandle, a complex of root diseases, including laminated root rot, may cover hundreds or even thousands of contiguous hectares of forest. Disease centers in these situations are seen as concentrations of mortality rather than discrete patches of infection. A mosaic of thin and moderately dense canopy areas in the forest is typically observed. Tree seedlings and saplings, as well as tall shrubs such as Rocky Mountain maple, ocean-spray, and Mallow ninebark, often grow particularly well in the areas of thin forest canopy.

In young plantations and young natural stands, seedlings of susceptible species that are planted or grow naturally near an infested stump may be killed within a few years (fig. 7), but because early mortality is scat-

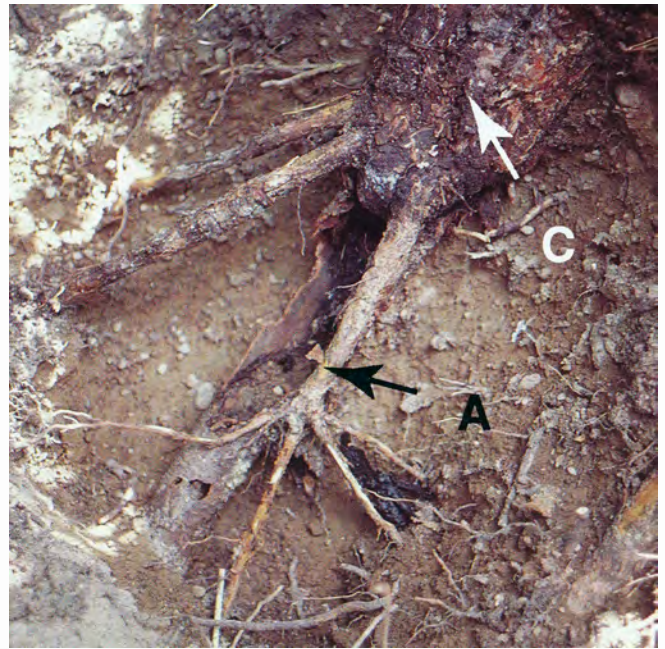


Figure 6—Callus tissue (C) often forms on roots of living trees where they break as a result of decay by *Phellinus weirii*; adventitious roots (A) developing from this callus may prolong the lives of infected trees.

tered and trees are small, the disease often is overlooked. In coastal stands, small groups of dead trees usually become evident in plantations 15 to 20 years old. In inland stands, typical disease centers usually do not develop until the stands are 20 to 30 years old.

Crown Symptoms

Crown symptoms caused by *P. weirii* are variable and usually develop only after the fungus has killed and decayed a major portion of the root system. Reduced height growth is usually the first crown symptom; it may be accompanied by a loss of needles, which gives the crown an increased transparency (fig. 8). As the disease progresses, terminal growth on branches declines until needles turn yellow and die. Where death of *P. weirii*-infected trees is hastened by bark beetles (family Scolytidae) or other agents, foliage often turns red. Douglas-firs infected by *P. weirii* may produce large crops of stress-induced smallish cones a year or two before they die (fig. 9). Crown symptoms similar to those induced by *P. weirii* may be caused by other agents that damage either roots or crowns; hence symptomatic trees should be examined closely to confirm presence of *P. weirii*. Small trees usually die soon after showing the first signs of infection, whereas larger trees often survive for decades after the first symptoms or signs of infection become evident. Trees that decline for many years typically develop a rounded or dome-shaped top, and branches may appear brushlike with most needles near branch ends (fig. 8). Some infected trees are windthrown before obvious crown symptoms develop.



Figure 7—Roots of susceptible seedlings planted near an infected stump may come in contact with the infected stump or infected roots, become infected, and be killed within a few years. The infected stump serves as long-lived inoculum that enables the fungus to remain on the site and initiate the disease in the replacement stand.

Tree age and site conditions appear to be important in the expression of crown symptoms. Crown symptoms may be more obvious in younger trees than in older ones, where symptoms are more variable. A tree more than 60 years old may have a normal appearing crown but have a substantial portion of its root system infected. Crown symptoms are likely to be expressed earlier on a poor site than on a good one.

External Root Appearance

Phellinus weirii can be identified on living infected trees by carefully brushing away the soil and examining the root collar and lateral roots for superficial (ectotrophic) mycelia. Typically the mycelia are grey-white to tawny

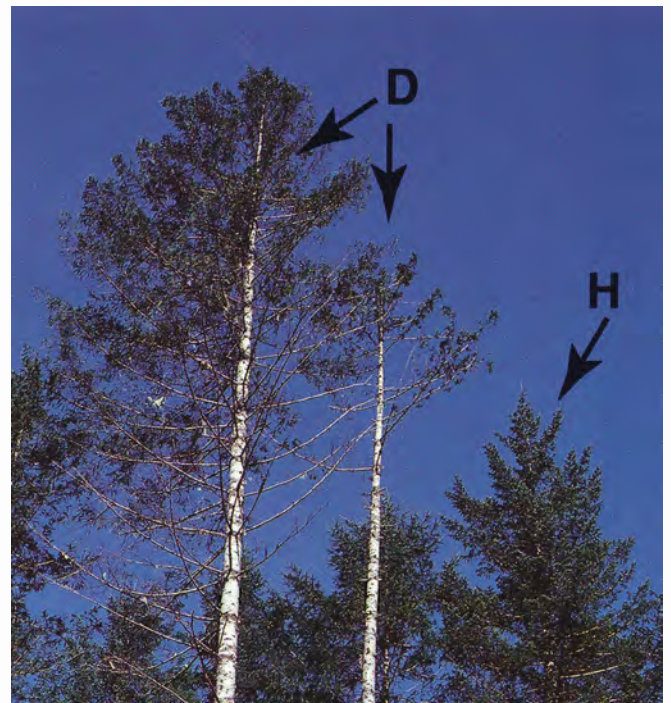


Figure 8—Laminated root rot causes changes in host crown shape and appearance. The two diseased (D) Douglas-firs in the foreground are at the edge of a disease center and have rounded tops (resulting from stunted height growth), bushy branch ends (resulting from reduced branch growth and shortened needles), and thinning foliage. The Douglas-fir on the right is healthy (H).



Figure 9—Douglas-fir infected by *Phellinus weirii*. Note the distress crop of smallish cones, reduced terminal growth, short branchlets, and fewer than normal needles.

to light purple and form a continuous sheath around the outer surface of infected roots with thin bark, often binding soil particles to the roots (figs. 10 and 11). With a hand lens, reddish-brown, wiry setal hyphae 0.3 millimeter (0.04 inch) long can be seen scattered in the superficial mycelia (fig. 12), in pockets within the bark (fig. 13), or in pieces of wood with advanced decay. Setal hyphae, found in ectotrophic mycelia or in advance decayed wood from a known host, are diagnostic of *P. weirii*. A brown (may be black if old), crustlike

mycelial growth often can be found over a felt of setal hyphae mixed with superficial mycelia on the bark below the duff layer. This is particularly noticeable in the crotches of roots (fig. 14) or in deep bark crevices. The crust is most easily found at the root collar and at root crotches but is also common on the undersides of roots and stumps. In trees with thick root bark, the ectotrophic mycelia containing setal hyphae are sometimes not evident on the bark surface but are found in pockets within the bark (fig. 13).



Figure 10—Light-colored ectotrophic mycelia often cover the surface of an infected root to form a sheath. This mycelial sheath can be seen by carefully brushing soil away from an infected root.

Figure 11—A sheath of ectotrophic mycelia usually covers the roots and belowground portion of the stem of a diseased seedling.



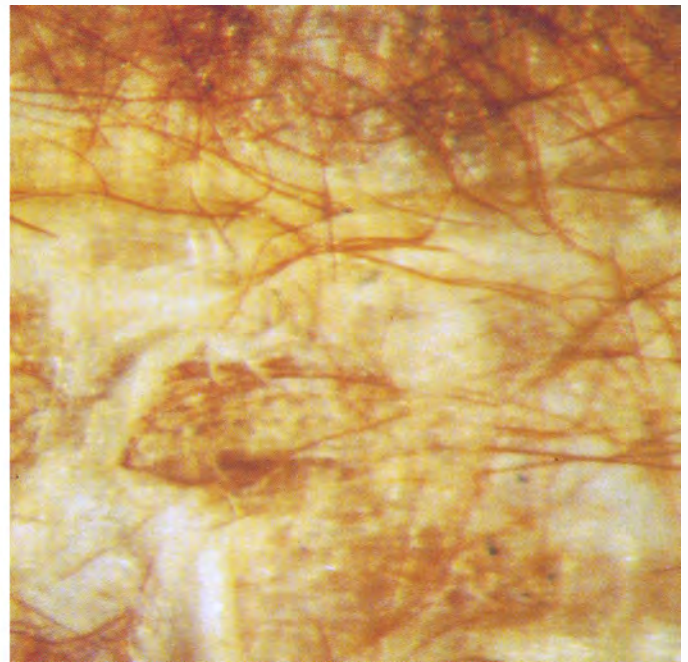
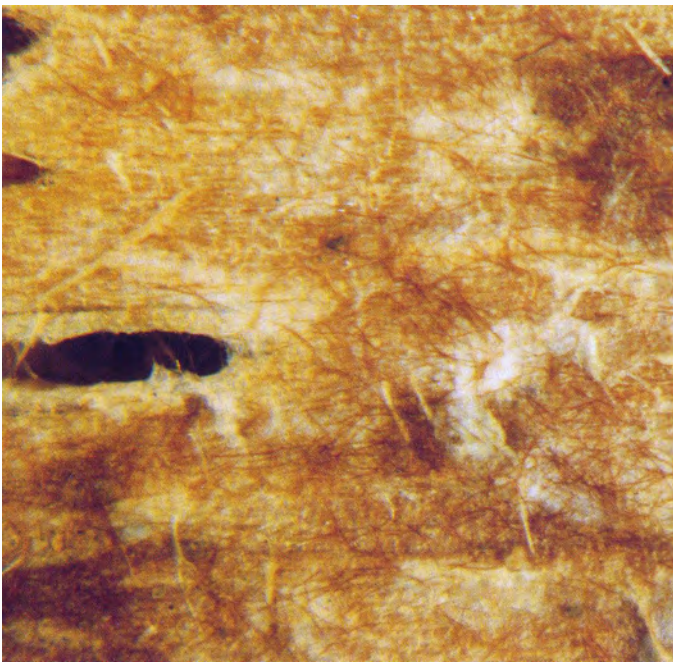


Figure 12—Reddish-brown setal hyphae can be seen scattered in the ectotrophic mycelium from a root: as seen on decayed wood when viewed through a hand lens (L) or at higher magnification on the root surface (R).

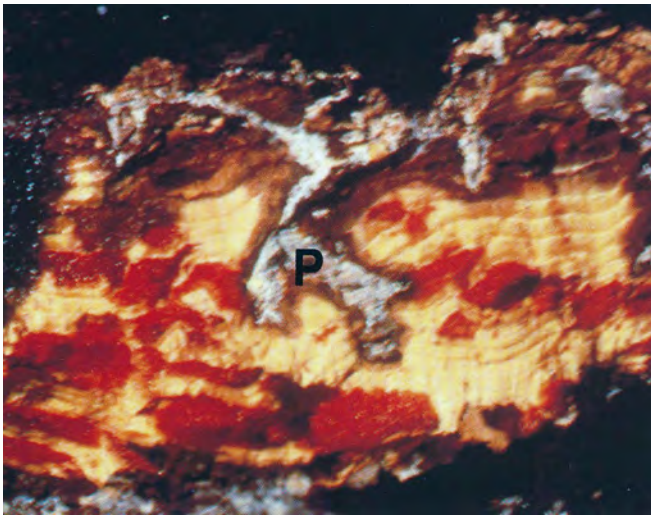


Figure 13—In thick root-bark, the ectotrophic mycelium with associated setal hyphae can often be found in pockets (P) and crevices in the bark, even when the mycelium is not on the root surface.

Colonized Wood

Colonized wood (occupied by the fungus) in early stages of decay appears as reddish-brown to chocolate-brown irregular patches or crescent-shaped stains on fresh stump tops or cross sections of major roots. Stain sometimes appears first in the sapwood or inner heartwood at stump height, but it more often occupies



Figure 14—Sometimes a brown crustlike mycelium of *Phellinus weirii* will form in patches on infected hosts belowground.



Figure 15—Characteristic incipient decay (stain) caused by *Phellinus weirii* as seen on fresh Douglas-fir stump tops. The stain is typically reddish brown to chocolate brown. Spots (a), which grow larger as more roots are involved in the disease (b), finally coalesce into a continuous ring just before the tree dies (c). Stain usually has distinct margins defined roughly by radii and annual rings (d).

the outer heartwood in association with the point of attachment of major infected roots. Later, as more roots become infected, the patches may spread and coalesce into a somewhat continuous ring (fig. 15). Along the grain, the stain appears as streaks or broad bands continuous with stain in the roots (fig. 16). In living trees, the stain usually extends less than a meter (3 feet) above stump height (fig. 17) but may extend to a height of 4 meters (13 feet). In direct sunlight, the stain begins to fade within a few days, so prompt examination is essential if stain is to be used for

detection. Advance decayed wood, which may appear on stump tops, the ends of broken roots of windthrown infected trees, or any exposed wood, has oval pits 0.5 by 1 millimeter (0.02 by 0.04 inch) and easily separates along annual rings as laminations—hence the common name “laminated root rot” (figs. 5 and 18). Thin, feltlike, velvety layers or sparse tufts of setal hyphae may develop between the sheets of wood (figs. 12 and 19). This laminated decay is a good indicator of the presence of the disease in a stand, particularly where most susceptible trees have died. As the decay progresses,

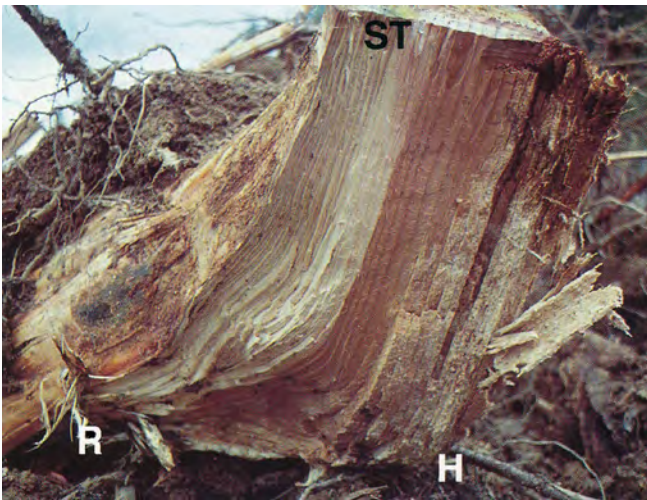


Figure 16—Stain seen on a stump top is continuous along the grain from an infected root (R) to the stump top (ST). In advanced stages of the disease, the stump wood often turns to a stringy mass with a hollow (H) at the root collar.



Figure 18—Typical laminated decay caused by *Phellinus weirii*. This piece of root delaminated at the spring wood into sheets, each the thickness of an annual ring.



Figure 17—Stain seen on a stump top continues up the bole, usually less than 1 meter (3 feet) but may extend up to 4 meters (13 feet).

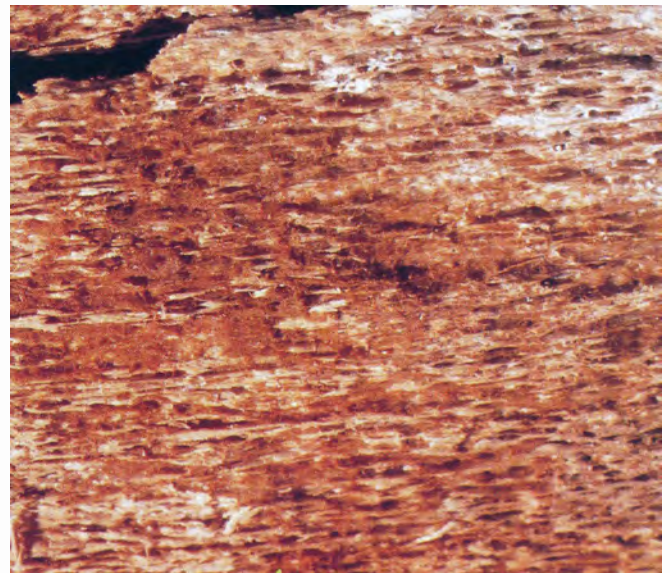


Figure 19—Masses of brown setal hyphae that form between layers of wood in late stages of decay by *Phellinus weirii* may look like brown felt.

the wood becomes a stringy mass and the lower bole may become hollow (fig. 7). For some roots or stumps, only a shell of bark remains.

In some stands, up to 15 percent of infected trees have a hollow center delineated by one or two growth rings (fig. 20). Such stumps, although associated with laminated root rot, indicate a form of the disease in which there are few, if any, infected roots associated with the stump.³

³Unpublished data, Walter G. Thies.



Figure 20—Tree bases may be made hollow at stump height by *Phellinus weirii* (left). Branch traces in the hollow are resin soaked and not decayed by the pathogen (right).

Inexperienced observers most often confuse laminated root rot with *Armillaria* root disease or with annosus root rot. Although all three diseases attack roots, they are easily distinguished. *Armillaria* root disease can be identified by white- to cream-colored mycelial fans that develop under the bark, and laminated root rot has characteristic ectotrophic mycelia that develop on the bark surface or in bark pockets in roots. Annosus root rot of some species (especially pines and true firs) may result in decayed wood that separates along annual rings, much like laminated root rot, but with more limited pitting and without the setal hyphae characteristic of laminated root rot.

Fruiting Bodies

The fruiting bodies (sporophores) of *P. weirii* are inconspicuous, pore-covered crusts that lie flat on the supporting surface and form on the underside of fallen trees, uprooted stumps, and occasionally the boles of dead standing trees. They usually develop near or in contact with the forest floor. When young, they are light grey-brown with light buff sterile margins (fig. 21). Later, they turn a uniform chocolate brown. In some years and in many areas, sporophores are rare or at least too inconspicuous to be of value in recognizing the disease. In interior stands, fruiting bodies are especially rare due to typically drier conditions thought to be unfavorable to sporophore development.



Figure 21—Young *Phellinus weirii* sporophore close to the duff on the underside of a Douglas-fir stem near the root wad.



Disease Cycle

Initiation

Laminated root rot begins in a stand when uninfected roots of a susceptible tree grow into contact with infested stumps or roots left from a previous stand and are colonized by *P. weirii* (fig. 7). As the new stand develops, the fungus spreads among living trees via root contact (Bloomberg and Hall 1986, Bloomberg and Reynolds 1982, Wallis and Reynolds 1965). Although both external superficial mycelia and internal mycelia of *P. weirii* are involved in spread and infection of new trees, external spread of the fungus is most common and successful (Reynolds and Bloomberg 1982). The fungus advances proximally and distally along newly infected roots and eventually penetrates through the bark to the host's cambium. Once inside host roots, the fungus progressively causes decay, resulting in reduced uptake of water and nutrients and weakened structural support to infected trees. Crown symptoms may appear 5 to 15 years after initial infection (Wallis 1976). After onset of crown symptoms, larger trees live an average of 10 years and show progressively more severe symptoms and concurrent growth loss (Bloomberg and Reynolds 1985; Thies 1982, 1983). As roots are progressively killed and decay, a tree eventu-

ally dies while standing or loses its structural support and is windthrown (fig. 4). Some hosts, with advanced decay in the bole, may break off aboveground (fig. 5). As the fungus spreads and kills adjacent trees, openings are created. These openings expand about 30 centimeters (1 foot) per year (Bloomberg 1984, Childs 1970, Nelson and Hartman 1975), usually in some variation of a radial pattern.

Inoculum

When infected trees die, the pathogen continues to live saprophytically in large infested stumps and large roots for as long as 50 years (Childs 1963; Hansen 1976, 1979) and in relatively small-diameter roots for at least 8 years (Thies and Hansen 1985, Wallis and Reynolds 1965). After 50 years, however, surface mycelia of *P. weirii*, which are responsible for most of the spread of the fungus, tend to remain only in discontinuous patches along a relatively small portion of infected roots (Hansen 1979). Longevity of the pathogen inside roots may be attributable in large part to zone lines commonly formed by *P. weirii* and several other higher fungi



Figure 22—Zone line (Z) and advanced decay (AD) in a Douglas-fir root infected by *Phellinus weirii*.

in colonized wood (Nelson 1973). Zone lines are formed as protective barriers to unfavorable conditions and other decay fungi or antagonistic organisms; they are visible as black lines when decayed wood is cut (fig. 22). Conversion of the pathogen from a saprophytic existence inside a root to active growth on the root surface, where it could spread and infect other roots, has not been demonstrated. Thus the relation of long-term survival of *P. weirii* in wood (such as in an old-growth stump) and ability to initiate infection in a new host is not well understood. Until information to the contrary becomes available, any stump or tree with internal viable *P. weirii* should be viewed as a potential source of inoculum and a threat to adjacent host trees.

Although viable basidiospores of *P. weirii* are dispersed from fruiting bodies in the forest, they are believed to be relatively unimportant in initiating new infections (Nelson 1976). Artificial inoculations with spores have not been successful, so the role of spores in spread of the fungus remains unclear.

Influence of Site

Survival and spread of *P. weirii* on infested sites and damage attributable to laminated root rot are likely influenced by site conditions. Soil factors, including temperature, pH, and moisture content, have been investigated (Angwin 1985) and may play a role in disease incidence and damage intensity. Specific ecological relations have been suggested for laminated root rot. For example, in northern Idaho a strong

association was found between laminated root rot and timber type, soil type, aspect, elevation (Williams and Marsden 1982), and habitat type (Byler and others 1990). Apparent severity and distribution of the disease will be determined by host availability, and the absence of highly susceptible species may confound interpretation of the influence of site factors. Moist western hemlock and western redcedar habitat types and the moister grand fir habitat types often have large areas nearly covering the type with scattered diseased trees. The level of mortality differs greatly but in general is higher on wetter than on drier habitat types (Byler and others 1990). Obvious root disease centers occur most frequently, however, where highly susceptible hosts predominate—on the drier Douglas-fir and grand fir habitat types (Williams and Marsden 1982). The predominance of less susceptible species may mask both the earlier losses of highly susceptible species and the risk to those species if they are reintroduced (Hagle and others 1992, Haig and others 1941). A study in the northern Oregon Coast Range found a significant association between laminated root rot and slope position in 70- to 100-year-old Douglas-fir stands. The percentage of plots containing *P. weirii*-infected Douglas-firs was highest on ridges and decreased downslope. No relation was found, however, between laminated root rot and plant community type or aspect (Kastner and others 1994). From sampling conducted in second-growth Douglas-fir stands in south-coastal British Columbia, it has been concluded that laminated root rot incidence and severity can be related to the biogeoclimatic ecosystem classification (BEC) used in the Province (Beale 1992, Bloomberg and Beale 1985). Some forest districts in British Columbia use the BEC system to rate laminated root rot hazard for areas or subzones. As yet no strong evidence exists that any individual site factor (or group of factors) is a reliable predictor of either the presence or intensity of laminated root rot in a particular stand.

Distribution Within a Stand

Distribution of laminated root rot within stands differs. Symptomatic, diseased trees often appear aggregated into fairly discrete infection centers, but the centers may be randomly dispersed in the stand (Childs 1963). In other stands, distribution may be diffuse and difficult to detect; in these cases *P. weirii* may not cause distinct centers but will affect groups of one to several trees throughout the area of infestation. The diffuse pattern was present in 10 stands (45 to 60 years old) in Washington and Oregon that were mapped (fig. 23) to record the location of *P. weirii* inoculum.⁴ In most of these stands the pattern of *P. weirii* infection was diffuse rather than aggregated, and in no case did openings accurately portray the distribution of the disease. Resource managers should be aware of the importance of correctly determining the distribution of the disease before selecting a disease-management strategy. Some stands have a mostly clumped distribution of *P. weirii* inoculum, and others have few openings and a

⁴Unpublished data, Walter G. Thies.

diffuse distribution. A management strategy that assumes clumped inoculum distribution is unlikely to yield the desired results if distribution is diffuse.

Disease Intensification

The amount of laminated root rot on a site at a given time and its ability to intensify are determined by the initial amount of inoculum, rate of disease spread, existence and distribution of hosts, and time since first infection. With a fungus such as *P. weirii* that is spread vegetatively rather than by spores, initial inoculum is particularly important in disease intensification. Inappropriate management strategies or operational techniques also may increase the disease; for example, repeated regeneration with highly susceptible species on a *P. weirii*-infested site likely will result in an increased incidence of the disease (Tkacz and Hansen 1982, Wallis and Reynolds 1965).

Unmanaged stands—In some unmanaged old-growth stands, inoculum is probably kept at a relatively low density by natural processes. These stands have fewer but larger trees than do second-growth stands, and relatively few trees will be infected. As a tree reaches advanced stages of the disease, it usually is wind-thrown, thereby effectively removing the root collar and often a lot of infected root material from the soil, reducing the amount of inoculum, and disrupting residual roots. Breaking of substrate continuity and subsequent invasion by antagonistic soil organisms likely reduce the period of residual inoculum viability. The openings created by falling trees may well support less susceptible conifers, nonhost shrubs, or hardwood tree species for many years before highly susceptible host species reoccupy the site. Thus, natural succession may provide time for the *P. weirii* inoculum to be rendered ineffective before host species occupy the site.

In some situations, most often in inland stands, hardwood and shrub species do not readily regenerate, and many susceptible conifer species are a natural part of the stand. In such places, laminated root rot openings will be continually regenerated by susceptible species, and little change is likely to occur in inoculum density from one generation to the next.

Managed stands—In contrast to the situation for unmanaged stands, management of second-growth stands of susceptible species probably encourages buildup of inoculum. A common scenario for such stands is this: at the time of conventional harvest, usually at age 50 to 70 years in coastal stands or 90 to 120 years in inland stands, some relatively large disease centers exist; they will contain down and standing dead trees among the live infected trees. As a result of harvest, nearly all standing live or dead infected trees will leave behind an infected stump and root system. The site is then immediately planted or regenerates naturally, often with Douglas-fir or another species highly susceptible to laminated root rot. Thus,

in managed second-growth stands, much of the original *P. weirii* inoculum is left undisturbed at harvest, and with the immediate reintroduction of a susceptible species, the incidence and intensity of the disease will increase. In starting with a diffuse but detectable infection and the absence of any successful intervention to mitigate effects of laminated root rot in managed stands, resource managers may lose more than half the predicted harvest volume after two or three rotations of a highly susceptible host like Douglas-fir.

Interaction With Bark Beetles

In many areas, a high proportion of *P. weirii*-infected trees are actually killed by bark beetles and not by the fungus. Bark beetles rarely kill healthy, vigorous trees. Rather, they prefer or are most successful on trees weakened by fire, drought, defoliating insects, injury, intense competition, or disease. Laminated root rot is a particularly significant predisposing agent. *Phellinus weirii*-infected Douglas-firs, 30 centimeters (12 inches) in diameter at breast height (d.b.h.) or greater, are commonly infested by Douglas-fir beetles (*Dendroctonus pseudotsugae* Hopkins), and smaller diseased Douglas-firs are generally hosts to Douglas-fir pole beetles (*Pseudohylesinus nebulosus* (LeConte)) or Douglas-fir engravers (*Scolytus unispinosus* LeConte). *Phellinus weirii*-infected white and grand firs are frequently infested by fir engravers (*S. ventralis* LeConte). Managers checking dead and dying trees should be aware of the common association between root diseases and bark beetles. The search for cause of death should not end with discovery of beetle galleries. Roots should be examined also for signs of disease (Goheen and Hansen 1993).

Phellinus weirii plays a significant role in maintaining endemic bark beetle populations over time. *Phellinus weirii* and other root diseases provide a continuous source of favorable host material for beetles between those times when conditions are favorable for epidemics.

Influence of Fire

Most natural and human-caused fires have little effect on the survival of *P. weirii* inoculum. Only those fires intense enough to destroy entire root systems affect survival of the fungus. Fire does influence root disease, though, by influencing species composition on infested sites. Conifer species most favored by fire are also those generally least susceptible to infection and damage by *P. weirii*. Hardwoods, which are immune to the fungus, are common postfire invaders. In areas with histories of frequent fires, root disease pockets probably remain relatively small because of a constant flux of low-susceptibility species. Where fire exclusion is most successful, there is an increase in the proportion of shade-tolerant, susceptible conifers and concurrently in the amount of laminated root rot.

Pedee - Area 24

Latitude 44° 47' N., Longitude 123° 33' W.

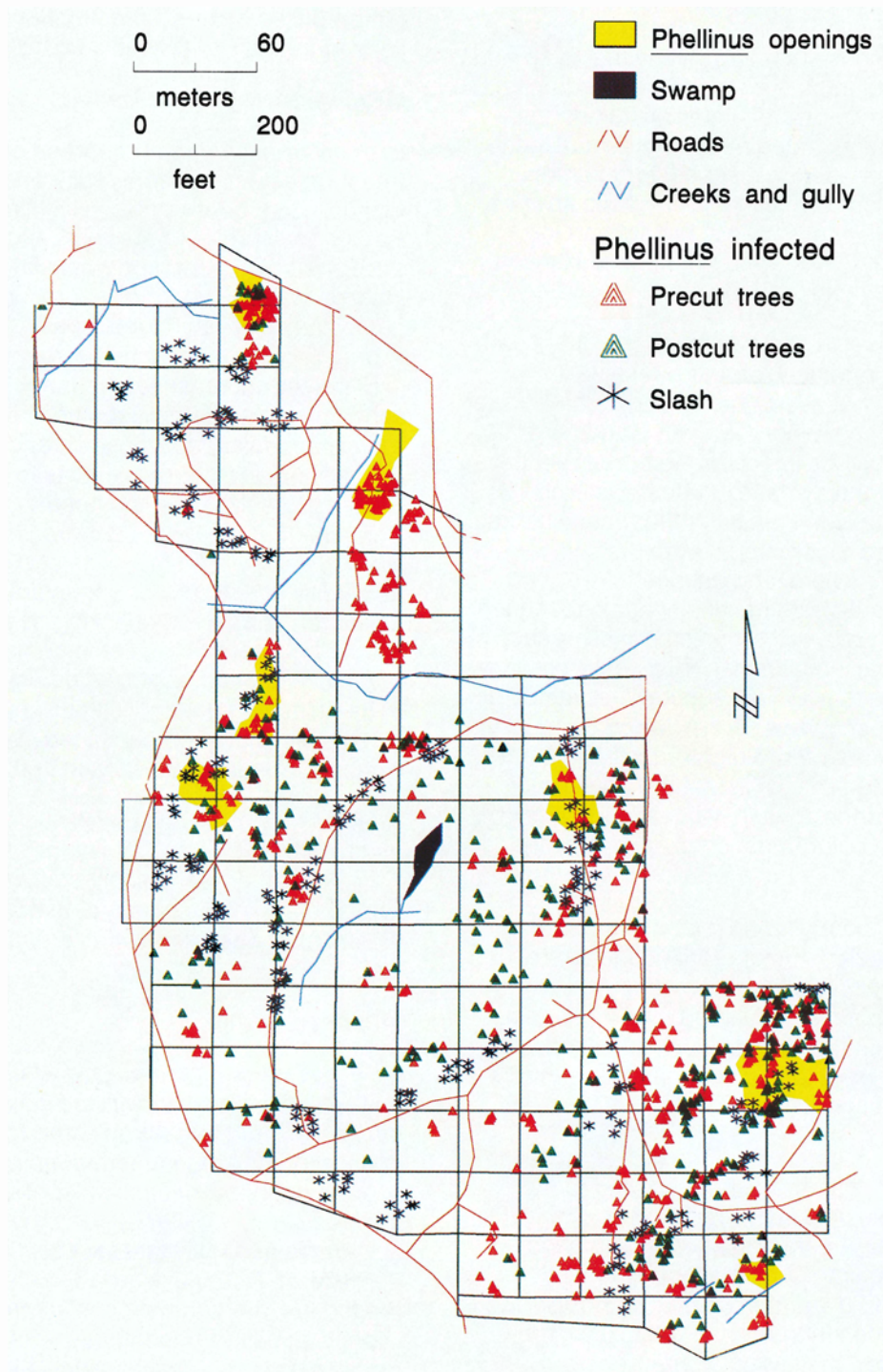


Figure 23—Map of a research study area in the Oregon Coast Range showing the aggregated (openings) and diffuse distribution of infected trees as determined by precut and postcut surveys. The stand covers almost 10 hectares (25 acres) and had 1,112 infected trees. The grid lines are about 30 meters (99 feet) apart.



Disease Management

Laminated root rot is often described as a “disease of the site.” The effect on any one stand depends on several stand and site characteristics, most notably the disease history, species composition, and density of the stand. Because *P. weirii* seemingly has no reliable method of long-distance spread, the disease likely will not appear in the next stand if it is not present in the current one. Further, the pathogen is not likely to be transferred to new stands by the movement of either forest residues or forest products because the fungus is very susceptible to drying and displacement by other organisms.

Standard responses to disease losses, such as shortened rotations or intensive salvage programs, capture much of the mortality loss but do little to reduce inoculum on the site or effects of the disease in the next stand. Proven management strategies unfortunately do not exist for reducing laminated root rot inoculum while maintaining highly susceptible species for a full economic rotation on infested sites. Several proposed management strategies are discussed here. In selecting strategies for infested stands, resource managers must consider many factors, including long-term

objectives, stand and site conditions, treatment costs and expected benefits, safety at recreation sites, the impact on desired wildlife habitat in some areas (including habitat required by endangered species), the impact of the disease on management objectives if nothing is done, and compatibility of the treatments with other landscape-level management considerations. No single mitigative strategy will be appropriate for all stands, and no effective strategy has yet been proposed that will eradicate *P. weirii*. Studies of several management strategies are currently underway, and new information will become available during the next few years as these studies are completed.

Phellinus weirii is a disturbance agent that generally increases ecosystem diversity. It selectively kills susceptible conifers and thus provides growing space for less susceptible conifers and immune hardwoods and shrubs. The disease causes openings in stands, develops areas of unique stand structure, and contributes greatly to the presence of snags and down woody debris. Knowing this, resource managers may elect a “no treatment” option for some diseased stands or

portions of stands, especially where wildlife habitat or visual objectives are enhanced by the disease.

Strategies During Stand Development

Management recommendations currently include surveying to determine the extent and magnitude of disease effects or inoculum load on the site, to locate all infection centers and mark a buffer around each, and to either replant the site with suitable, less susceptible tree species or reduce the amount of inoculum. Intensive silviculture treatments, such as vegetation control and fertilization, help increase the volume recovered from a diseased site and shorten the time needed for remaining crop trees to reach harvestable size. These treatments will not make host trees less susceptible to infection by *P. weirii*, however. The ability of *P. weirii* to infect and colonize roots is not correlated with tree vigor (Goheen and Hansen 1994).

Survey—The first and most important step in developing a management strategy for a stand with laminated root rot is to assess the root disease. This may be done in several ways, such as ground surveys or remote sensing. Personnel conducting surveys must be well trained and experienced in identifying signs and symptoms of the disease.

Before harvest—After *P. weirii* has been confirmed in a stand, disease distribution and intensity should be determined. This information is critical to successfully managing the disease. Resource managers should be aware that the design and intensity of root disease surveys differ among regions and jurisdictions, depending on the experience and preferences of personnel who develop and conduct the surveys and on the kind of information required. Survey data also provide information required to develop and use root disease models.

Survey designs range from regularly or randomly spaced transects to systematically spaced, variable- or fixed-radius plots. For example, distribution and size of disease centers and total area affected can be estimated by using variations of the following: (1) an interval traverse grid method (suggested 50-meter [160-foot] interval) is established and crews sketch map centers based on aboveground symptoms only; (2) a transect-intercept method that uses aboveground symptoms and presence of pathogen-specific signs, such as superficial mycelia, setal hyphae, or pitted laminated decay; or (3) aerial photographs may be used where species composition, age, and past disturbance do not obscure root disease signatures (Bloomberg and others 1980a, 1980b; Hadfield and others 1986; Morrison and others 1992; Williams and Leaphart 1978). Relative levels of root disease severity have been efficiently assessed for inland stands by using 1/25,000-scale true color or color infrared aerial photographs (Hagle 1993, Hagle and others 1992).

This method is used routinely to characterize the root disease in ecosystem management project analyses in northern Idaho and western Montana. Problems have been encountered when aerial surveys have been used to estimate the area affected by root disease in stands of pole-size and larger trees west of the crest of the Cascade Range.

After harvest—Although surveys of laminated root rot-affected stands are necessary to plan any management activity, if a mitigative strategy (such as inoculum removal) is planned after harvest, then an after-harvest survey may be necessary to further assess the extent of the disease. Before harvest, openings are easy to locate and map; however, only obvious openings, down trees, or trees with severe crown symptoms will be detected. If the disease has a diffuse distribution, many infected trees will be missed and survey results will not accurately estimate disease distribution and intensity.

Timber fallers familiar with the stain and decay caused by *P. weirii* may provide assistance to after-harvest surveys by marking the stump tops of infected trees with distinctive chainsaw cuts. They could, for example, make an "X" or shallow parallel cuts perpendicular to the hinge (fig. 24). Stump tops marked with chainsaw cuts can be readily identified after logging or slash burning, the presence of the fungus confirmed, and the locations noted on a map. Although most infected stumps will be found after harvest by using this procedure, a few will be missed because the fungus has invaded the roots but has not yet reached stump height and caused the characteristic stain. Alternatively, after-harvest surveys can be conducted, and infected stumps can be mapped or marked with paint or tags.

Precommercial stands—If root disease centers are numerous and widely distributed in sapling stands, consideration should be given to destroying the plantation and either replanting with immune or low-susceptibility species or reducing inoculum and replanting with any suitable species. Although this option may be unattractive because of lost time and investment, the treatment could significantly increase final yield. It is also possible to mitigate disease impacts during precommercial thinning. Immune and low-susceptibility species should be retained to create barriers to the spread of *P. weirii* by preventing root contacts between susceptible trees. An area with scattered dead and dying individual trees could be interplanted with tolerant or immune species. If distribution of inoculum in a stand is known to be aggregated and not diffuse, trees in disease centers and an adjacent buffer could be removed to reduce spread of the fungus to the rest of the stand. If stocking needs to be increased, resistant or immune species can be planted in disease centers and buffers.

Commercial stands—Commercial thinning is a stand improvement operation, and managers should consider



Figure 24—Infected stumps can be marked in a durable manner by making shallow grooves in the stump top with a chainsaw just after the tree is cut. This is often done with an “X” or parallel lines perpendicular to the hinge.

the probable combined effects of thinning and root disease on leave trees before deciding to thin. It is generally not recommended that infested stands of highly susceptible species be entered for commercial thinning if the disease is present in 20 percent or more of the stand. In Idaho and Montana, commercial thinning is not recommended if highly susceptible species make up more than 30 percent of the leave trees.⁵ A final decision should be based on distribution of disease and insect problems, stand structure and composition, and management objectives. If the disease is present in less than 20 percent of the stand, commercial thinning may produce desirable results. Some variation of three thinning strategies is generally used:

1. Thin through—The stand is thinned without regard to the disease. This strategy is used when the probability of windthrow is low and final harvest will occur within 15 years.
2. Buffer-strip removal—All trees in centers and those within 15 meters (50 feet) of visibly infected trees or stumps are cut. The decision to cut all trees or only highly susceptible species depends on management objectives for the site. This strategy is used when the goal is to prevent spread of the disease into healthy portions of the stand. Buffer-strip removal will increase the opening size and therefore may increase the probability of windthrow (see “Buffer Removal,” p. 24).
3. Avoid-center—Avoid cutting trees within 15 meters (50 feet) of visibly infected trees or stumps. This strategy is used when thinning the stand will increase the probability that losses to windthrow will be greater than losses to disease.

⁵Personal communication, Susan K. Hagle, U.S. Department of Agriculture, Northern Region, Cooperative Forestry and Pest Management, Missoula, MT.

Thinned stands should be monitored closely to determine the need for salvage entries.

If the disease occurs in small, discrete pockets or is limited to certain portions of the stand, the stand can be stratified, with healthy portions thinned as usual and diseased portions treated appropriately.

Strategies at Stand Regeneration

The best opportunity to manage laminated root rot or reduce inoculum occurs at final harvest when powerful equipment is available and has room to maneuver, when harvest and reforestation options are available, and when stump treatments or soil amendments can be applied most easily.

Inoculum removal—

Stump removal—For gently sloping, high-quality sites with light soils, removing stumps (stumping) with a wide-tracked excavator is an effective management strategy for laminated root rot (see “Equipment—The History,” p. 26). Stump removal is expensive, however, and can disturb or appear to disturb the site. Removal of infected stumps and large roots eliminates most inoculum from infested sites and minimizes carryover of the disease into the new stand. Small-diameter roots and pieces of large-diameter roots that remain in the soil after stump removal are torn and fragmented and invaded by competing soil organisms. Although these small pieces of infested wood may have sufficient inoculum potential to kill young regeneration, they are unlikely to serve as long-term inocula.

Stump removal significantly reduces mortality from *P. weirii* (Morrison and others 1988, Thies and others 1994), but the effects on subsequent tree growth are variable. It increased the growth of Douglas-fir for at least 15 years after planting in some cases (Morrison and others 1988, Thies and Nelson 1988), had no effect

on seedling growth in some cases (Thies and others 1994), and had a negative effect in still others (Smith and Wass 1994). Negative effects were attributed in part to soil compaction caused by heavy equipment. Effects of compaction and methods proposed to ameliorate those effects are reviewed elsewhere (Froehlich 1985, Froelich and McNabb 1984, Lull 1959, Smith and Wass 1991).

Successful stumping operations require an excavator that is large enough to easily undermine a root system, has the ability to pull and lift a stump or stump sectors, and has tracks wide enough and far enough apart to provide a minimum of ground pressure and operate safely on uneven ground (fig. 25). From experience gained during research studies, specifications can be suggested for the smallest excavator that can be used to extract second-growth Douglas-fir stumps and root systems (see "Excavator Specifications," p. 26). These specifications provide a starting point for selecting equipment to remove stumps less than 70 centimeters (28 inches) in diameter (Bloomberg and Reynolds 1988, Thies 1995). Stump removal costs differ signifi-

cantly based on site factors and local labor and equipment rates.

Push-falling—Push-over harvesting, or push-falling, is an alternative to postharvest stumping. Whole trees are pushed over, which causes root systems to be pulled from the soil; harvesting and removal of diseased stumps and roots is thus achieved with one stand entry. An excavator pushes a tree over (fig. 26) and then shakes the root wad to remove soil. The excavator is used to rake the resulting hole to break up, expose, and remove residual root pieces. Finally, trees are bucked into logs and the root wads cut off either at the excavation site or at the landing. Push-falling of Douglas-fir up to 78 centimeters (31 inches) d.b.h. is both operationally effective and cost-effective for reducing *P. weirii* inoculum on many sites in British Columbia (Morrison and others 1992, Sturrock and others 1994). Like stumping, push-falling is best suited to high-quality sites where either Douglas-fir or grand fir, or both, is the preferred species; slopes are less than 30 percent; and soils textures are sandy to sandy loam. The operations should be conducted when soil



Figure 25—A large excavator with a standard bucket and an optional gripping thumb can be used effectively for stump removal.

moisture is low. Although site disturbance is inherent to push-falling operations, site degradation can be minimized or prevented by careful planning and by employing experienced operators. The long-term efficacy of push-falling is not yet known, but it is expected to be comparable to postharvest stumping.

Fertilization—In the early 1970s, results from field trials suggested that *P. weirii* inoculum could be reduced by high dosages of nitrogen fertilizer (Nelson 1975). Success was attributed to the effect of nitrogen on increasing the activity of soil microorganisms that

competed with or were antagonistic to *P. weirii*. Field trials which followed demonstrated that, although nitrogen fertilization increases Douglas-fir seedling growth, it has no effect on seedling mortality caused by *P. weirii* (Thies and Nelson 1988, Thies and others 1994). Monitoring of these field studies continues, but it is anticipated that fertilization will not have a significant impact on incidence of laminated root rot.

Chemical inactivation—Treating stumps with fumigants (fig. 27) is one way to reduce inoculum of some root-rotting fungi and may be a useful tool for managing laminated root rot without causing mechanical site damage. The fumigant chloropicrin has been shown to eliminate *P. weirii* from infested stumps and reduce the volume of roots supporting vigorous *P. weirii* by up to 93 percent in less than 2 years (Thies and Nelson 1987). Other fumigants have been demonstrated to significantly reduce the volume of *P. weirii* inoculum in Douglas-fir but have not yet been registered for use: methylisothiocyanate, Vapam, Vorlex, and Telone II-B (Fraser and others 1995, Thies and Nelson 1982). Fumigants also have been shown to reduce the volume of roots occupied by *P. weirii* in living Douglas-fir without killing the tree (Thies and Nelson 1994). Although fumigation of stumps reduces the fungus in roots, the relation of reduced inoculum to reduced root disease in the next rotation is not clear. Long-term studies will establish this and determine the effect of fumigation on nontarget organisms (Ingham and others 1991, Thies and others 1991).

Fumigants may be an option for the future management of sites infested by *P. weirii*. In 1989, the U.S. Environmental Protection Agency approved a label allowing the use of chloropicrin to reduce inoculum of *P. weirii* in Douglas-fir stumps. Despite this approval, current public attitudes and policies about pesticides likely will limit the use of fumigation to sites where disruption associated with stump removal is unacceptable, such as in areas of steep terrain or fragile soils, or in the treatment of relatively small areas of high-value trees.

Biological agents—The search continues for organisms that can be introduced into stumps to reduce *P. weirii* inoculum in infested stands. *Trichoderma viride* Pers. and other species in this genus are well-documented antagonists to wood decay fungi, which suggests their use as biological control agents for laminated root rot (Nelson 1964, 1973). Progress was made in this approach when *Trichoderma* spp., introduced into holes bored in *P. weirii*-infested stumps, colonized the diseased wood immediately around the introduction holes (Nelson and Thies 1985, 1986).

The use of naturally occurring antagonists to eliminate *P. weirii* from stumps and roots is an intriguing possibility, but problems remain: suitable virulent antagonists must be found that are capable of rapid colonization of *P. weirii*-infested stumps and roots, systems must be



Figure 26—An excavator can be used to push-fall trees.



Figure 27—The fumigant chloropicrin being pumped into predrilled holes in a *Phellinus weirii*-infested stump.

Buffer Removal

Buffer removal, or cutting a strip of trees between an expanding laminated root rot center and the adjacent portion of the stand that is judged to be healthy, is a mitigative strategy suggested for laminated root rot. Because it is believed that the fungus requires live roots to spread, cutting trees to create a buffer zone of dead roots around an infection center should protect the rest of the stand from becoming infected. Buffer removal is not a new concept as evidenced by its many previous names: (1) clearcutting—cutting out the larger foci and about 20 meters (66 feet) into the surrounding stand (Childs 1955); (2) narrow clearcuts—clearcutting narrow areas at the edge of infection centers (Childs 1963); (3) surround cutting—cutting a swath of at least two trees beyond symptomatic trees (Wallis 1976); (4) patch-cut—cutting all susceptible trees in disease pockets and those within about 15 meters (50 feet) of visibly infected trees or stumps (Hadfield and Johnson 1977); (5) removing pathway trees—cutting all symptomatic host trees and neighboring nonsymptomatic host trees occurring within a zone that extends two normal tree spacings beyond trees with sparse, yellow foliage (Hadfield 1985); and (6) bridge tree removal—cutting all trees (likely infected trees plus bridge trees) within 10 meters (33 feet) of laminated root rot center boundaries (Sturrock and Fraser 1994).

An early test of the buffer removal concept looked at the effect of trenching on the spread of laminated root rot in a 20-year-old Douglas-fir stand (Wallis and Buckland 1955). Two trenches, each 30 centimeters wide and 45 centimeters deep (12 by 18 inches), were dug: the first was around a disease center; the second, parallel to the first and 8 meters (25 feet) away, isolated a buffer of nonsymptomatic trees. When the trial was terminated 20 years later, the trenches were credited with having prevented the spread of the fungus into the isolation zone despite the fact that some trees within the zone had died from laminated root rot. One explanation of this anomaly is that there were some nonsymptomatic-infected trees in the isolation zone at the time of trenching. This result should serve to caution resource managers that the establishment of buffers around disease centers may not completely isolate the disease and protect the uninfected portion of the stand.

A root disease survey should be conducted before buffer removal is seriously considered. If the survey shows that the disease occurs in discrete centers and final harvest is more than 10 years away, buffer removal will likely prevent spread of the disease and may be worth doing. If distribution of the fungus is diffuse, then infected trees outside of centers will serve as foci for disease spread and buffer removal may waste resources and unnecessarily sacrifice potential crop trees.

developed for proper handling and introduction of antagonists into stumps, and where necessary, treatments must be developed to enhance the activity of antagonists. Although progress has been made, development of practical biological controls likely will take many years.

Reforestation choices—

Species manipulation—Tree species that are of low-susceptibility (tolerant or resistant) or immune to *P. weirii* (see table 1, p. iii) can be established on sites infested with the fungus to reduce inoculum or to hold

the effects of the disease within acceptable limits. The choice of alternate species for infested sites will be limited by both site conditions and the silvics of the species. It is apparent that conifer species differ in their susceptibility to the pathogen. The susceptibility ratings in table 1 are based on inoculation tests and field observations and trials over several years, and represent a near consensus of pathologists working in western North America.

The attractiveness of planting low-susceptibility species to reduce the impact of laminated root rot has caused

considerable effort to be focused on this approach in the last two decades. Concepts that have been or are currently being tested include planting low-susceptibility species; planting a mixture of immune or low-susceptibility species with susceptible species to break continuity of susceptible root systems and thereby slow spread of the disease; and rotating the conifer crop with immune species (hardwoods).

Preliminary results from planting low-susceptibility species show little or no mortality from laminated root rot. Preliminary results from mixed species plantings suggest that this approach does not significantly reduce mortality of susceptible species (Wallis 1976). Of hardwoods used in field trials, red alder has received the most attention because of its hypothesized function as "a natural biological control of laminated root rot" (Nelson and others 1978). Red alder functions as a productive occupier of the site by keeping susceptible host species out while producing desired benefits (fiber, cover, and site enhancement), thus allowing time for *P. weirii* inoculum to die. Studies with red alder continue.

As a practical matter, while research continues on other strategies, species manipulation remains the strategy of choice on sites heavily infested by *P. weirii*. With the crest of the Cascade Range in the United States and the crest of the Coast Range in British Columbia as dividing lines, to the west red alder, bigleaf maple, western redcedar, and western white pine are planted, and to the east, pines (lodgepole, ponderosa, and western white), western larch, incense-cedar, and hardwoods are used as alternative species. In south-west Oregon, the recommended alternative species, depending on the site, include ponderosa pine, sugar pine, western white pine, incense-cedar, western redcedar, and hardwoods.

In northern Idaho, western Montana, and the Blue Mountains of Oregon and Washington, increasing species diversity is the strategy of choice for reducing losses to *P. weirii*. Commercial tree species resistant to or tolerant of *P. weirii* include western white pine, ponderosa pine, lodgepole pine, western larch, and western redcedar. Although western hemlock may prove to be resistant to killing by *P. weirii*, it often develops extensive butt rot. Uncertainty about the ability of this species to survive for extended periods in the presence of the pathogen suggests caution when using this species on infested sites.

Resistant Douglas-fir—Given the long life of a natural stand, the near ubiquitous distribution of *P. weirii* in Douglas-fir and grand fir timber types, and the ability of the fungus to survive in stumps and roots for extended periods, it might be expected that highly susceptible species, such as Douglas-fir, would have been reduced to scattered pockets. Yet, this is not the case; these species thrive in extensive stands. The total area of commercial forests with reduced fiber production due to

laminated root rot is significant, but less than might be expected, given the spread rate of the pathogen. The cause for moderation in disease losses is undetermined but may be associated, at least in part, with variable resistance within host species.

Differential resistance of Douglas-fir to attack by *P. weirii* is reported by Buckland and others (1954), who suggest that trees showing tolerance to the fungus are those able to compensate for killed roots by producing callus tissue and adventitious roots (fig. 6) and thus maintain their vigor. Differential resistance of rooted cuttings to infection by *P. weirii* was observed among selected Douglas-fir clones (Entry and others 1994). Another host response to infection may be the active production of either mechanical or chemical defenses, which limit the wood colonized by the pathogen. Evidence of this can be seen in stumps having centers hollowed by *P. weirii* (fig. 20), but excavation and examination reveal no sign of the fungus in any of the major roots. These are only two of likely many forms of host adaptation to *P. weirii*. Whether these responses are genetically controlled, environmentally controlled, or a combination of the two is not known. Additional research is needed on *P. weirii*-host interactions. As yet, tree improvement programs have not been established to select trees with apparent resistance to *P. weirii*.

Spacing strategy—Proper spacing and location of seedlings may greatly reduce laminated root rot development in infected coastal Douglas-fir stands. Observations made during stump and root excavations in three coastal stands each growing on sites with deep soils, led to the conclusion that there are few root contacts between Douglas-fir aged 60 years or less and spaced at least 4 meters (13 feet) apart.⁶ Thus, if trees in regenerating stands are at least 4 meters apart and growing in deep soil, their roots should not frequently come in contact until sometime after stand age 60. The following spacing strategy is proposed for infested coastal stands with deep soils: plant seedlings at a normal spacing, then thin as soon as possible after the stand is considered established but before stand age 10 years. Select as crop trees those seedlings furthest from residual stumps and spaced at least 4 meters apart. Stands may have to be treated at 5-year intervals to remove volunteer seedlings of host species. The goal of this strategy is to lengthen the normal time to closure of the root systems in the replacement stand. Although some seedlings will contact residual inoculum and die from laminated root rot, secondary infections, which would normally occur across root contacts in a dense stand, will be reduced. Rooting habit of Douglas-fir will differ depending on the soil type. This strategy is less likely to be successful where the soil conditions encourage a shallow, spreading root habit.

⁶Unpublished data, Walter G. Thies.

Modeling

Over the past two decades, significant progress has been made to incorporate the effects of root diseases into growth and yield models. In the Western United States, the Western Root Disease model, an extension of the Forest Vegetation Simulator model (formerly called PROGNOSIS) has been developed. In British Columbia, two models—the Tree and Stand Simulator (TASS) and the *P. weirii* Root Rot Simulator (ROTSIM)—have been linked to predict spread and impact of laminated root rot (Mitchell and Bloomberg 1987). Users supply information on stand structure, site, disease, and inoculum condition as either keywords or numeric input to the models. Based on host presence and stand information, the models then calculate the rate of spread of the fungus and the number of trees within diseased areas that will become infected. The models can simulate the combined effects of root disease, windthrow events, or management activities such as stump removal that may reduce inoculum in stands. The Western Root Disease model also can simulate the combined effects of root disease and bark beetle attack. With the development of user-friendly guides and training sessions, resource managers in the United States are able to integrate the Western Root Disease model into their stand analyses (Stage and others 1990). Validation of the TASS-ROTSIM model is currently underway in British Columbia, with the goal of producing managed-stand yield tables for use by resource managers.

Excavator Specifications (minimum)

Operating weight: 20,000 kilograms
(45,000 pounds)

Power: 118 horsepower

Bucket reach: 11 meters (36 feet)

Bucket width: 1.0 meter (3 feet)

Bucket capacity: 1 to 1.75 cubic meters
(1 to 2 cubic yards)

Machine width: 3.2 meters (10 feet)

Track pad width: 80 centimeters
(30 inches)

Hydraulic thumb

Source: Thies 1995.

Equipment—The History

The equipment recommended for stump removal has changed significantly since the mid-1970s as a result of both research and operational activities. Traditionally, stumps were removed by using a bulldozer with a solid blade, which moved more soil than was desirable. Large holes were created and topsoil was mixed with subsoil. A bulldozer with a toothed (brush) blade successfully removed stumps but with little movement and mixing of soil. Use of log forks on a bulldozer caused even less soil disturbance. Log forks, with 1 meter (3 feet) long, tusklike projections that point forward and curve up slightly, were pushed into the soil on either side of a stump, and pushed or pried the stump from the soil. As the stump was lifted and shaken, much of the soil clinging to the roots fell back into the hole. Forks produced smaller holes, moved and mixed less soil, and probably removed more infested roots than did blades. A vibrating stump puller combines lift and vibration to separate stumps and root systems from the soil with little site disturbance (Arnold 1981). This equipment has been successful at removing stumps up to 50 centimeters (20 inches) in diameter. Recently, excavators with a standard bucket and a hydraulically operated gripping thumb (fig. 25) have been recommended for stump removal for both operational and research purposes (Bloomberg and Reynolds 1988; Thies 1987, 1995). This equipment can dig or lift stumps while its tracks remain stationary, thereby causing less compaction and disruption than equipment that relies on a pushing force. Much of the site and soil damage caused by older techniques resulted from tracks moving and slipping when the force necessary was applied to push the stumps out.

Synopsis

Laminated root rot, caused by *P. weirii*, is a serious root disease affecting Douglas-fir and other commercially important species of conifers in northwestern North America. The disease is estimated to reduce timber volume and growth by over 4 million cubic meters (157 million cubic feet) annually.

Laminated root rot is often first detected during ground surveys when stand openings with windthrown and standing dead diseased trees are observed. These opening or disease centers differ in size from one to several hectares and may be occupied by hardwoods or disease-tolerant conifer species.

Crown symptoms caused by *P. weirii* include reduced terminal growth, yellowing, and stress-induced cone crops. Specific signs of the fungus include ectotrophic mycelia on roots, reddish-brown stain in infected roots or on stump tops, laminated decay, and distinctive setal hypha associated with ectotrophic mycelia or advance decayed wood.

Phellinus weirii is only known to spread by root contact between infected trees or infected stumps and susceptible trees. The fungus infects and decays host roots, which results in reduced uptake of water and nutrients and weakened structural support. As the fungus spreads and kills more trees, characteristic stand openings appear and expand at about 30 centimeters (1 foot) annually.

When infected trees die, the pathogen may continue to live saprophytically for at least 50 years in colonized, old-growth stumps and for several decades in second-growth stumps. The inoculum potential of colonized stumps decreases with time. Basidiospores dispersed by the fungus are believed to be unimportant in initiating new infections.

The occurrence and distribution of *P. weirii* and the effect it has on any one stand will depend on several factors, including site conditions, stand age, and the disease history of the stand. The presence of *P. weirii*-infected trees may increase other pest problems in a stand, such as bark beetle activity. Accurate assessment of disease distribution in stands through a root disease survey is a necessary precursor to the selection of disease management strategies.

There are several management strategies for laminated root rot. A resource manager will choose an appropriate strategy based on several factors, including stand age and site conditions, local economic or other constraints, and desired outcomes. Strategies may be applied during stand development through modifications to planting or thinning regimes. Most strategies for managing laminated root rot are best conducted at the time of stand regeneration when inoculum can be reduced through stump removal or other means or when tree species that are immune or of low susceptibility to the fungus can be planted. Research continues on management strategies and on integrating knowledge of laminated root rot into growth and yield models.

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Laminated root rot, caused by *Phellinus weirii* (Murr.) Gilb., is a serious root disease affecting Douglas-fir and other commercially important species of conifers in northwestern North America. This report gives an overview of the disease as it occurs in the Pacific Northwest in Canada and the United States. Information on recognizing crown symptoms and signs of the disease is presented. The disease cycle of laminated root rot, from initiation to intensification and distribution within infected stands, is described. Finally, disease management strategies during stand development and at stand regeneration are discussed. Features on the nomenclature of the fungus and on its management by silvicultural and mechanical approaches also are included. The report is intended as a general reference for a wide audience.

Keywords: *Inonotus sulphurascens*, laminated root rot, *Phellinus sulphurascens*, *Phellinus weirii*, *Poria weirii*, root diseases.

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