# Characteristics and Consequences of Root Diseases in Forests of Western North America

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Root diseases are somewhat mysterious. Operating as they do within the soil, it is difficult to actually view root pathogens or follow their progress in causing disease. The signs and symptoms that they produce can be quite subtle and variable. Just identifying which pathogen occurs in a specific situation is often challenging. Nevertheless, in the past two decades, forest managers have become increasingly aware of the important roles that root disease organisms play in forests and the significant influences that they exert on our ability to attain desired management objectives.

Root pathogens usually affect groups of neighboring trees in progressively expanding disease pockets or centers. These centers generally contain dead trees that have died at different times over several years and living but infected trees in various stages of decline. They are commonly characterized by much lower stocking levels than surrounding healthy portions of stands, and they also may contain numerous windthrown or broken trees on the ground. Root disease centers vary in size from those involving only a few trees to those covering hundreds of acres. They may be very discrete or they may involve a scattering of affected trees dispersed over a larger area.

On individual trees, crown symptoms associated with most root diseases are similar and include reduced height growth, loss of needles, chlorotic foliage, death of branches, production of distressed cone crops, and, ultimately, host mortality. Accurate identification of which root pathogen or pathogens occur in an area usually requires digging to expose roots, and removing bark from roots and root collars to reveal the inner wood. Often laboratory culturing or more sophisticated techniques such as isozyme and DNA analyses are necessary to identify the biological species or strain of the causal fungi. Although a number of root diseases are found in the West, three are considered to be the most significant. These are laminated root rot, caused by the fungus *Phellinus weirii*; Armillaria root disease, caused by *Armillaria ostoyae*; and Annosus root disease, caused by *Heterobasidion annosum*. The impacts of these fungi on forest stands are modelled in the Western Root Disease Model, Version 3.0. A general understanding of their biology is presented in the next few pages to enhance the reader's ability to input data and interpret outputs.

## Laminated Root Rot

Laminated root rot caused by the fungus *Phellinus weirii* (Murrill) R.L. Gilbertson is distributed from the Six Rivers National Forest in California north to northern Vancouver Island, British Columbia and east to western Montana. It is probably the most important tree disease of coastal forests in the Pacific Northwest and also has significant impacts in interior forests (Hadfield 1985, Hadfield and others 1986, Hagle and others 1987, Nelson and others 1981, Scharpf 1993, Thies 1984, Thies and Sturrock 1995, Wallis 1976).

Laminated root rot is distinguished by the characteristic decay that it produces in roots and butts of

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infected hosts. The decayed wood separates easily at the annual rings, is often heavily pitted on both sides of each layer, and has diagnostic reddish-brown to pinkish setal hyphae between the layers. *P. weirii* also forms a grayish-white to buff-colored mycelial sheath, referred to as ectotrophic mycelia, on root surfaces of young trees and within bark crevices on older trees. Fruiting bodies of *P. weirii* are appressed brown, crusty structures with numerous pores that occasionally form on the undersides of downed trees or on exposed roots close to the ground. They are of little diagnostic value because of their rarity and cryptic nature.

On highly susceptible hosts, *Phellinus weirii* causes extensive decay of roots and death of the tree by destroying the roots' ability to take up water and nutrients or predisposing them to windthrow or bark beetle infestation. Less susceptible hosts develop butt rot. All western conifers can be infected by *P. weirii*, but some tolerate the pathogen better than others. Douglas-fir, [*Pseudotsuga menziesii* (Mirb.) Franco], white fir [*Abies concolor* (Gord. & Glend.) Lidl. ex Hildebr.], grand fir [*Abies grandis* (Dougl. ex D. Don) Lindl.], Pacific silver fir [*Abies amabilis* Dougl. ex Forbes], and mountain hemlock [*Tsuga mertensiana* (Bong.) Carr.] are highly susceptible and are readily infected and killed by the fungus. Other true firs, spruces (*Picea* spp.), western hemlock [*Tsuga heterophylla* (Raf.) Sarg.], and western larch [*Larix occidentalis* Nutt.] are considered to be intermediately susceptible; they are often infected but rarely killed by *P. weirii*. Pines and cedars are tolerant or resistant; they are rarely infected and almost never killed by the fungus. All hardwoods are immune to *P. weirii*.

Laminated root rot is a disease of the site. *Phellinus weirii* spreads very little if at all by windborne spores. Virtually all spread involves mycelial growth on or in host roots. The fungus survives a long time (as much as 50 years) in roots and stumps of dead or cut trees that were infected prior to death. The fungus does not colonize dead wood, in part because it is not a good competitor with other fungi. In infected trees that die or are cut, disease-induced resin impregnation of wood surrounding infections and the ability of *P. weirii* to form a protective sheath around itself are responsible for the pathogen's long-term survival. The fungus survives only in the portion of the host's root system that it occupied at the time of host death. The fungus spreads to new hosts when their roots contact colonized roots of infected stumps or snags and the fungus grows onto and colonizes them in turn. Formation of disease centers involves subsequent tree-to-tree spread via root contacts. *P. weirii* does not grow through soil but grows on root surfaces at a rate of about 0.33 to 0.67 meter per year. Detailed information on this disease and its biology, control, and management implications are given by Thies and Sturrock (1995).

## Armillaria Root Disease

Armillaria root disease is widely distributed throughout the West and is common in many forest stands (Hadfield and others 1986, Hagle and others 1987, Morrison 1981, Scharpf 1993, Shaw and Kile 1991, Williams and others 1986). However, it acts differently in different areas and on different sites, even some that are quite close to each other. In general, Armillaria root disease is more severe in interior than in coastal forests.

Armillaria root disease is identified on the basis of the occurrence of thick, white mycelial fans under the bark of roots and lower stems of affected trees. On trees that have been dead for some time, mycelial fans fade in color to yellow and eventually disintegrate. However, they leave a fan-shaped impression on the inner bark that can usually be seen for some time after the mycelium itself is gone. Trees infected by *A. ostoyae* almost always exhibit various amounts of basal resin flow or brownish leachate, often in very substantial amounts. Other species of *Armillaria* occur in forests primarily as saprophytes. These *Armillaria* species also may produce mycelial fans under the bark of dying or dead trees, but they are thinner and are not associated with resin flow. The combination of thick mycelial fans and resinosis characterizes infection by *A. ostoyae*. Trees infected by *A. ostoyae* also frequently have black string-like fungal structures called rhizomorphs on their roots or under their bark and exhibit a decay that is yellow, stringy, moist, and malodorous. *A. ostoyae* produces honey-colored mushrooms in autumn on or near dead trees and stumps.

*Armillaria ostoyae* kills the cambium of susceptible host roots and root collars, girdling the tree. Infected trees are often predisposed to bark beetle attack and usually die standing. Windthrow is rare. All

western conifers and some hardwood trees and shrubs can be infected by *A. ostoyae*. Off-site plantings, wounded trees, and trees growing on compacted soils or in areas with drainage problems are particularly likely to be affected. Tree susceptibility may differ with locale. In coastal forests, *A. ostoyae* is most commonly observed killing Douglas-firs and true firs in plantations under 30 years old. After age 30, trees become increasingly tolerant of the pathogen and are much less frequently killed. In interior forests, *A. ostoyae* commonly causes more mortality than in coastal situations, and host susceptibility may differ from site to site. True firs are usually the most susceptible hosts, Douglas-fir the second, and other species tend to be tolerant or resistant. However, there are areas where pines are very susceptible and some sites where almost all tree species are killed. Because of these differences, it is necessary to analyze host susceptibility on a site-by-site basis. In interior forests, Armillaria root disease often is most evident in partially cut stands where there are numerous wounded residual trees and compacted soils. It is often clearly associated with the occurrence of large conifer stumps and, in some areas, with hardwood shrubs or hardwood tree stumps.

*Armillaria ostoyae* may be spread on rare occasions by windborne spores that probably infect through wounds or stump surfaces. However, in most cases, Armillaria root disease, like laminated root rot, is a disease of the site. *A. ostoyae* survives for up to 35 years in previously infected stumps and snags. It spreads to nearby susceptible regeneration by growth across root contacts or, less commonly, via rhizomorphs that grow for short distances (about one meter) through soil. Tree-to-tree spread continues by these same avenues at a rate of about 0.33 to 0.67 meter per year. Further details on the biology and management of Armillaria root disease are presented by Shaw and Kile (1991).

## Annosus Root Disease

Annosus root disease, caused by *Heterobasidion annosum*, occurs in conifer forests throughout the Northern Hemisphere. It is common and widely distributed in western North America (Hadfield and others 1986, Hagle and others 1987, Morrison and others 1986, Otrosina and Scharpf 1989, Scharpf 1993). However, like Armillaria root disease, it acts differently in different areas.

Annosus root disease can be somewhat difficult to diagnose. The most reliable way to identify the disease in the forest involves finding its fruiting bodies, called "conks." Conks of *Heterobasidion annosum* are formed in or on stumps, on the roots of windthrown trees, and sometimes in or just under the duff layer on roots and root collars of standing hosts. Conks are shelf-shaped with dark concentrically furrowed upper surfaces, creamy white sterile margins, and white lower surfaces with numerous tiny pores. They are perennial and thus may have more than one pore layer. Dead and symptomatic hosts as well as still healthy-appearing individuals associated with stumps, snags, or trees exhibiting *H. annosum* conks will be infected in most cases.

Infection by *Heterobasidion annosum* is often characterized by reddish-brown staining in the roots and lower stems of trees. Resinosis is often associated with infected tissues. Some hosts also exhibit white or buff-colored fungal pustules on their roots. Advanced decay caused by the fungus is variable. It is often laminated with pitting only on one side of the layers and no evidence of setal hyphae. It can also be stringy and moist with white streaks and scattered black flecks. This latter appearance is most common on hosts that develop butt rot. Where necessary, presence of *H. annosum* can be confirmed by culturing wood chips on media and identifying the microscopic fruiting bodies of the asexual state of the fungus, *Spiniger meineckellus* (Olsen) Stalpers.

The fungus is genetically complex. There are several biological species that are not morphologically distinct but are genetically diverse (Otrosina and others 1992). These strains cannot be distinguished on the basis of appearance, but they are intersterile and differ markedly in pathogenicity and host range. In western North America, a "P-strain" that affects mainly pines and an "S-strain" that affects mainly true firs, hemlocks, and Douglas-fir have been identified. On living trees, there is little or no host crossover between the two strains. Unlike living trees, stumps offer no host specificity with respect to biological species and may become infected by either the S or P strains.

These two strains, or biological species, and the variation between tree species and site factors interact to make the host response to Annosus root disease infection highly variable. *Heterobasidion*

*annosum* kills resinous hosts directly by decaying roots and killing the cambium around the root collar. Trees are often predisposed to bark beetle infestation and usually die standing. Some non-resinous hosts are affected in the same way, but others develop extensive butt decay rather than being killed outright. Older butt-rotted trees (150 years old or greater) often break and fall. White fir, grand fir, and Pacific silver fir are often killed by the pathogen; other true firs and hemlocks usually suffer butt rot. Pines, especially ponderosa pines, are widely infected; however, substantial mortality in these hosts is usually limited to very dry sites. Douglas-fir is severely affected in portions of the Rocky Mountains, but is rarely affected further west.

*Heterobasidion annosum* is capable of spreading over long distances. Conks release basidiospores that are windborne and can be dispersed over distances of up to 100 miles. Spores that land on freshly cut stump surfaces or fresh wounds germinate, and the fungus colonizes the tree or stump. Subsequently, the pathogen can grow via root contacts into surrounding hosts, creating disease pockets. Rate of radial spread across roots is about 0.5 meter per year, but the fungus does not grow through soil. New disease foci are usually associated with large host stumps (0.5 meter or greater in diameter), and *H. annosum* can survive in large stumps for considerable time periods (up to 60 years). Annosus root disease is especially common in stands that have had partial-cut harvests. It is most severe in stands that have experienced several entries. More detailed information on Annosus root disease may be found in Otrosina and Scharpf (1989).

## Root Disease Impacts

It is difficult to find any forested area in the Western United States that has no root diseases. Though West-wide surveys are lacking, numerous smaller surveys done at the stand, watershed, Ranger District, or National Forest level suggest that laminated root rot, Armillaria root disease, and Annosus root disease can be found singly or together over significant proportions of the areas occupied by their hosts. It is estimated that the three major root diseases occur on 7 to 10 percent of the area occupied by coastal forests and 10 to 25 percent of the area occupied by interior forests (Gedney 1981, Goheen and Hansen 1993, Smith 1984). These fungi have co-evolved with their hosts for eons and until a few decades ago were in an equilibrium in forest ecosystems. However, it is apparent that root disease incidence is on the increase. Fire exclusion and management activities such as partial-cut logging and planting of diseased sites with susceptible hosts have favored their spread and intensification. In some areas, stand manipulations have altered ecosystems, and the forest conditions where the trees and root disease fungi were co-existing have been disrupted so they now favor the fungi. The result is similar to the introduction of exotic pests—a rapid increase in pathogen populations and catastrophic effects on host mortality.

Root diseases influence species composition, stand structure, stand density, and direction and rate of forest succession wherever they occur. They are agents of diversity, winnowers of weakened trees, natural thinning agents, and, in some cases, arbitrators of age structures. Basically, root pathogens operate by preferentially killing susceptible hosts. In affected areas, tree species and/or other plants that are tolerant, resistant, or immune to the particular fungi are favored.

From the perspective of a forest manager, the significance of root diseases will differ with management objective. Where timber production is a major concern, root diseases are viewed as being very destructive. Surveys done in rotation age stands show that basal area of live trees in portions of stands where root diseases are present is 10 to 55 percent less than that of adjacent healthy stands, translating into significant volume losses (Bloomberg and Reynolds 1985, Filip and Goheen 1984, Goheen and Hansen 1993, Lawson and others 1983). Root diseases also cause chronic, sub-lethal infections that do not result in dramatic symptom expression but reduce tree growth and vigor. Furthermore, because there are relatively small numbers of trees dying in any one year, salvage opportunities are not as great with root diseases as they may be with other disturbance agents, such as insects or fires, that kill large numbers of trees all at the same time.

Root diseases are also considered very damaging in developed recreation sites because of the high degree of hazard represented by infected trees. Root-diseased trees pose considerable threats to facilities and recreationists because of their increased windthrow potential.

Where wildlife habitat, visual quality, or watershed protection are major management objectives,

root diseases may be viewed as damaging, innocuous, or even beneficial. Effects of the diseases such as small openings in otherwise close-canopied stands, areas of plant species diversity, and groups of dead and down trees can be quite desirable because of associated increases in browse, low cover, small animal prey populations, cavity nesting sites, stand textural differences, and fall colors. However, root diseases can also reduce canopy cover to below desired levels, cause loss of preferred large tree character, and contribute to unacceptable fuel loads. Generally, root diseases are most likely to be considered management concerns when infection centers are large and many trees are being killed over substantial portions of a landscape.

## Root Disease Management

There are silvicultural options for managing root diseases. The most common form of management prescription involves species manipulation. In infected areas, tree species that are highly susceptible to the particular root pathogen or pathogens present are discriminated against, and more resistant species that are adapted to the site are favored. Species can be manipulated at the time of final harvest or during intermediate stand entries. An alternative approach involves inoculum reduction. Infected stumps are physically removed from the soil in infection centers, eliminating as much of their colonized root systems as possible. This kind of treatment minimizes likelihood of new regeneration contacting infected material, and, if conscientiously done, may allow sites to be regenerated with susceptible tree species. Some special treatments aimed at certain root disease pathogens are also available. For example, infection of newly created stumps by *H. annosum* can be prevented by treatment with borate compounds.

In making decisions about how to deal with root diseases in their prescriptions, planners need to clearly define their management objectives and carefully consider the likely long-term effects of the diseases in light of the desired future condition for the area under consideration. Clearly, planners will benefit greatly from a predictive tool that enables them to compare future conditions in healthy stands with those infected by root disease, the impacts of various levels of root disease, and the relative effects of different management prescriptions on root diseases. The Western Root Disease Model is such a tool.

## References

Bloomberg, William J.; Reynolds, Gordon. 1985. **Growth loss and mortality in laminated root rot infection centers in second-growth Douglas-fir on Vancouver Island.** Forest Science 31: 497-508.

Filip, Gregory M.; Goheen, Donald J. 1984. **Root diseases cause severe mortality in white and grand fir stands of the Pacific Northwest.** Forest Science 30: 138-142.

Gedney, Donald R. 1981. **The occurrence of laminated root rot on non-federal timberlands in Northwest Oregon.** Res. Note PNW-381. Corvallis, OR: Pacific Northwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture: 7 p.

Goheen, Donald J.; Hansen, Everett M. 1993. **Effects of bark beetles and pathogens in forests.** In: Schowalter, R.D.; Filip G.M., eds. Beetle-pathogen interactions in conifer forests. San Diego, CA: Academic Press; 175-196.

Hadfield, James S. 1985. **Laminated root rot, a guide for reducing and preventing losses in Oregon and Washington forests.** Portland, OR: USDA Forest Service, Pacific Northwest Region; 13 p.

Hadfield, James S.; Goheen, Donald J.; Filip, Gregory M.; Schmitt, Craig L.; Harvey, R.D. 1986. **Root diseases in Oregon and Washington conifers.** Portland, OR: USDA Forest Service, Pacific Northwest Region; 27 p.

Hagle, Susan K.; Tunnock, Scott T.; Gibson, Kenneth E.; Gilligan, Carma J. 1987. **Field guide to diseases and insect pests of Idaho and Montana forests.** Publication No. R1-89-54. Missoula, MT: USDA Forest Service, Northern Region; 123 p.

Lawson, Thomas T.; Berg, Allen B.; Handen, Everett M. 1983. **Damage from laminated root rot at the Black Rock Management Research Area in western Oregon.** Forest Research Laboratory Res. Note 75. Corvallis: Oregon State University; 7 p.

Morrison, Duncan J. 1981. **Armillaria root disease: a guide to disease diagnosis, development, and management in British Columbia.** BC-X-203. Victoria, BC: Environment Canada, Canadian Forestry Service, Pacific Forest Research Centre; 15 p.

Morrison, Duncan J.; Larock, M.D.; Waters, A.J. 1986. **Stump infection by *Fomes annosus* in spaced stands in the Prince Rupert Forest Region of British Columbia.** Information Report BC-X-285. Victoria, BC: Canadian Forest Service, Pacific Forestry Centre; 12 p.

Nelson, Earl E.; Martin, Neil E.; Williams, Ralph E. 1981. **Laminated root rot of western conifers.** Forest Insect and Disease Leaflet 159. Washington, DC: USDA Forest Service; 6 p.

Otrosina, William J.; Chase, Thomas E.; Cobb, Fields W., Jr. 1992. **Allozyme differentiation of intersterility groups of *Heterobasidion annosum* isolated from conifers in the western United States.** Phytopathology 82: 540-545.

Otrosina, William J.; Scharpf, Robert F. 1989. **Proceedings of the symposium on research and management of Annosus root disease (*Heterobasidion annosum*) in western North America;** 1989 April 18-21; Monterey, CA. Gen. Tech. Rep. PSW-116. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 177 p.

Scharpf, Robert F., technical coordinator. 1993. **Diseases of Pacific Coast conifers.** Agric. Handb. 521. Washington, DC: Forest Service, U.S. Department of Agriculture; 199 p.

Shaw, Charles G. III; Kile, Glen A. 1991. **Armillaria root disease.** Agric. Handb. 691. Washington, DC: Forest Service, U.S. Department of Agriculture; 233 p.

Smith, Richard S. 1984. **Root disease-caused losses in the commercial coniferous forests of the western United States.** Report No. 84-5. Fort Collins, CO: USDA Forest Service, Forest Pest Management, Methods Application Group; 21 p.

Thies, Walter G. 1984. **Laminated root rot, the quest for control.** Journal of Forestry 82: 345-356.

Thies, Walter G.; Sturrock, Rona N. 1995. **Laminated root rot in western North America.** Gen. Tech. Rep. PNW-GTR-349 [Resource Bulletin PNW-GTR-349]. Portland, OR: Pacific Northwest Research Station, Forest Service, U.S. Department of Agriculture; 32 p. In Cooperation with Natural Resources Canada, Canadian Forest Service, Pacific Forestry Centre.

Wallis Gordon W. 1976. ***Phellinus* (Poria) *weirii* root rot, detection and management proposals in Douglas-fir stands.** Forestry Technical Report 12. Victoria, BC: Environment Canada Forestry Service; 16 p.

Williams, Ralph E.; Shaw, Charles G.; Wargo, Phil M.; Sites, William H. 1986. **Armillaria root disease.** Forest Insect and Disease Leaflet 78. Washington, DC: USDA Forest Service; 8 p.