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BMPMSC Management Guide

Root Diseases in Conifer Forested Communities in the Blue Mountains of Northeastern Oregon and Southeastern Washington–Detection and Management, Values and Impacts

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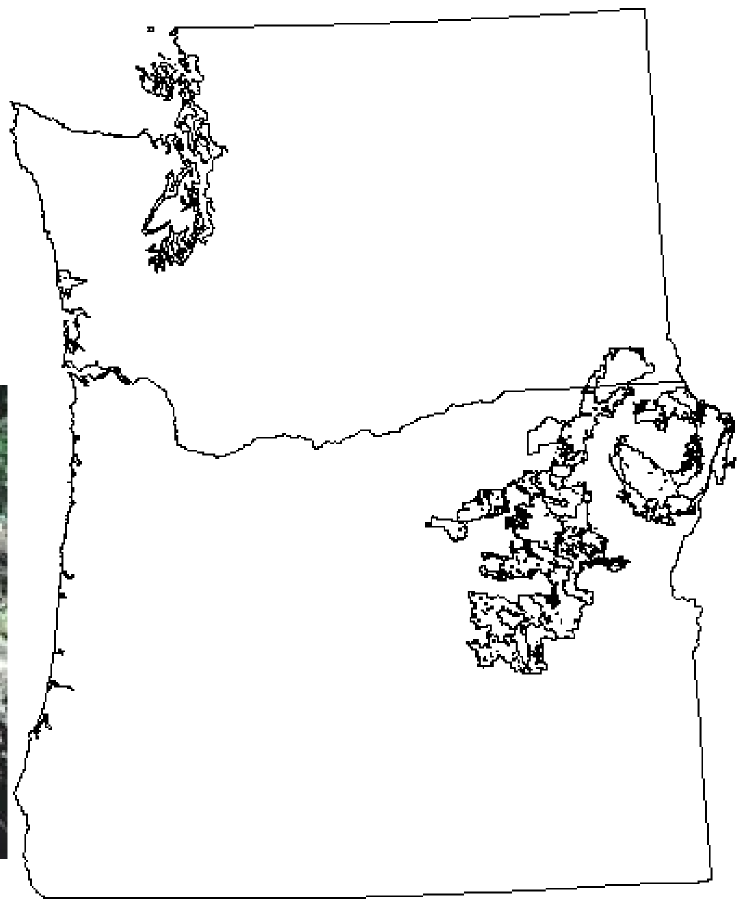

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INTRODUCTION

Several different root diseases are common in the Blue Mountains, killing conifers singly or in various size groups, often creating openings or gaps in stands, and adding to the down woody material on the forest floor. Root diseases function as natural disturbance agents, usually at endemic levels, providing structural and species diversity in coniferous plant communities. Years after timber management began in the Blue Mountains, land managers began noticing tree mortality associated with root diseases in some stand types. Sometimes root diseases were recognized as the cause of tree death, but most often mortality was attributed to bark beetles. More recently, root diseases have increasingly been recognized as being quite common as well as for the rather extensive mortality they may cause.

Until recently, root diseases were widely considered almost entirely detrimental to forest production and stand health. Treatments were designed to reduce, as much as possible, short-term losses, land out of wood fiber production, and future stand susceptibility. More recently, heightened concern for other resource values and changing management emphasis have caused land managers to reexamine the philosophy and implementation of heavy-handed root disease control. Rather, recent strategies for management of healthy ecosystems includes accepting the effects of endemic root disease activity. This includes recognizing the benefits provided to a wide variety of plants and animals. The snags and downed wood, disease pocket edges, and openings in the forest canopy enrich the diversity and abundance of wildlife. The key will be identifying the desirable endemic level of root disease activity and implementing the management action that will maintain that level. Possibly, a good starting point would be estimating and then emulating the natural range of variability of root disease occurrence and severity that existed under historical stand conditions.

Most root diseases are believed to have increased in their virulence and occurrence` throughout many forest types in the Blue Mountains for a variety of reasons. The benefits provided by an endemic level of root disease activity can give way to a variety of site and vegetation risks and impacts when disease severity increases beyond those levels. Epidemic root disease activity will detrimentally alter stand composition and structure, directly and indirectly impacting a variety of associated resources. Of most concern are the increased risks of excessive fuel loading, and build-up of tree-killing insects, especially bark beetles, as well as unacceptably high losses of wood fiber productivity. In many of these situations, compelling cases can be made to reduce root disease activity to lower endemic levels.

Four root pathogens result in most of the disease effects and management concerns in the Blue Mountains Province: Armillaria root disease, annosus root disease, blackstain root disease, and laminated root rot. Two less-damaging root and butt rot diseases, tomentosus root and butt rot, primarily of Engelmann spruce; and schweinitzii root and butt rot, mostly of Douglas-fir and western larch, are considered to be mostly endemic, functioning within their HRV, and will be only briefly discussed.

This paper will serve to provide most important information for managers and resource specialists concerning the primary root diseases in the Blue Mountains. As the causal fungal pathogens are different, root diseases differ in preferred hosts; signs and symptoms (recognition); tree, stand, and vegetation community effects; as well as spread, effective management; and an approximation of the natural range of variability of occurrence and severity.

Root diseases traditionally have been difficult to recognize, or mortality was misidentified as being caused solely by bark beetles. Proper identification is important in prescribing effective management. A key is provided on page 10 to help distinguish between various root diseases and other likely causes of conifer mortality. Root diseases typically appear similar at the stand level; pockets of dead and dying trees exhibiting long-term periodic mortality often in radially expanding centers. Even root disease effects to individual affected trees are similar; height growth is reduced, crowns deteriorate and after a period of years, mortality occurs. Verification of the causal root disease requires close inspection of affected trees, especially the diseased roots. Table 1 lists symptoms and signs of the four important root diseases in the Blue Mountains.

With the exception of blackstain root disease, the primary difficulty in successful management of root disease-infected communities are the long-term persistence in the soil of the causal fungi, that is, pathogens living as saprophytes on dead root systems, usually for decades, and infecting susceptible trees that encounter this material via root contacts. Secondly, all the important root diseases have the ability to intensify and spread under certain stand conditions that are increasingly prevalent. Blackstain root disease requires living hosts to be maintained on the site, but seems to persist well by spreading along grafted root systems in ever-enlarging centers, and is also maintained by several root-feeding vectoring insects that can spread the causal fungus longer distances, causing new infections on hosts as they feed. Most root diseases spread long distances by airborne spores; some very effectively, others only occasionally.

Root diseases help provide susceptible host material to forest insects, especially various bark beetles. Trees weakened by root diseases are attractive to bark beetles as a result of their reduced vigor and resistance. Abundant numbers of susceptible hosts result in increased beetle populations, that in turn, can infest other diseased trees as well as nearby green healthy trees. Other species of beetles can be maintained in recently-killed material provided by ongoing root disease mortality. In some cases, these populations can cause problems to healthy trees during times of environmental-induced stress, particularly drought. Similarly, high endemic beetle populations maintained by abundant root disease can rapidly and fully colonize downed or damaged hosts following severe weather events and epidemic populations can quickly develop.

Trees in the Blue Mountains differ in susceptibility to infection and resulting damage to each of these root diseases. Table 2 lists four levels of root disease susceptibility to native conifers in the Blue Mountains.

HISTORIC RANGE OF VARIABILITY

The question regarding the "natural" level of root diseases is frequently asked. Ecosystem restoration strategies may specify historical levels of root disease as the "baseline" normal level characteristic of a healthy condition. Data from the pre-European American settlement period does not of course exist, but levels of root diseases under historical conditions were believed to have been substantially lower than current levels because:

1. Species of shade tolerant, fire intolerant conifers that are most susceptible to root diseases have proliferated due to the exclusion of ground fire, selective harvesting of seral pines and larch, and active suppression of stand replacement fires.

2. Site disturbances, especially soil damage done during wet seasons, often associated with high trail density of ground-based skidding, and multiple-entry selective harvesting have resulted in residual tree wounding that increases the incidence and severity of some root diseases.

3. Expansion of conifer host vegetation preferred by defoliating insects and increased density of hosts throughout the mixed conifer type have intensified the impacts associated with the Douglas-fir tussock moth (*Orgyia pseudotsugata*), and the western spruce budworm (*Choristoneura occidentalis*). Trees weakened by these insects are rendered more susceptible to other pests, especially bark beetles and root diseases.

4. Stump infection by airborne spores of *Heterobasidion annosum* following harvest, especially of true firs, and in some cases ponderosa pine, will result in the increase of incidence of annosus root disease, caused by *Heterobasidion annosum*. In recent years on specified sites, protection of freshly-cut stumps from infection by airborne spores by application of granular borax, has been done to prevent annosus root disease from becoming established in stumps and subsequently infecting nearby trees across root contacts.

5. Research is currently investigating the response of populations of disease-vectoring root feeding beetles to certain site and stand disturbances, and the resulting incidence of blackstain root disease.

6. Lack of fire will change soil chemistry and is believed to change soil fungi population dynamics, perhaps allowing the pathogen *Armillaria ostoyae,* cause of

armillaria root disease, to become more competitive, and thus, cause more infection.

There are several ways of estimating historical root disease occurrence and virulence, none of which are entirely satisfactory. Hessburg *et al.* (1999) used changes in host type from historical and current aerial photographs and an insect and disease hazard rating system to estimate relative changes in pest activity. Hessburg *et al.* (1994) discusses trends that have occurred between pre-European settlement times and present conditions and the main factors involved but was unable to provide quantitative data.

Schmitt *et al.* (1991) did a field-based stand exam study and compared unentered stands on one Forest, the Wallowa-Whitman, with two levels of management disturbance in three broad groups of stand types (Table 3). This study had actual stocking data, but did not consider the many changes that had occurred because of lack of fire. Additionally, there probably was a substantial amount of hidden disease that was not detected because trees were not destructively sampled. This data is not representative of the entire Blue Mountains and is known to underestimate two localized root diseases, blackstain root disease, and laminated root rot.

Table 1. Symptoms and signs of four important conifer root diseases in the Blue Mountains.

Symptoms and Signs	Laminated root rot	Annosus root disease	Armillaria root disease	Blackstain root disease
Reduced terminal growth	X	X	X	X
Off-color foliage	X	X	X	X
Reduced needle retention	X	X	X	X
Distress cones	X	X	X	X
Rapid tree death			X	X
Tree death with no foliage loss			X	
Abundant basal pitch flow			X	
Black-brown stain in sapwood				X
Roots extensively decayed	X	X		
Live trees windthrown	X	X		
Associated bark beetle activity	X	X	X	X
Fleshy mushrooms produced at base of trees after autumn rains			X	
Mycelial fans or felt under bark of the root collar and roots			X	
Leathery conks		X		
Setal hyphae	X			
Resin-soaked dead roots		X	X	X
Ectotrophic mycelium	X	X		
Tawny-colored corky pustules produced on root surfaces		X		
Advanced Decay:				
Decay delaminating on annual rings with pitting on both sides of sheets	X			
Decay delaminating on annual rings with pitting generally on one side of sheets		X		
Yellow, stringy decay with abundant zone lines			X	
White, stringy decay with scattered black flecks		X		

Table 2. Relative susceptibility of Blue Mountain conifers to important root diseases.

Hosts	Laminated root rot	Annosus root disease	Armillaria root disease	Blackstain root disease
Western larch	3 (2 in trees >180 years)	4	3	4
Ponderosa pine	4	2 (1 in southern Malheur NF)	1 or 2	1
Lodgepole pine	4	3	3	4
Western white pine	4	3	3	4
Grand fir	1	1	1	3
White fir	1	1	1	3
Subalpine fir	2	1	1	4
Douglas-fir	1	3 (2 in eastern Pine RD, Wallowa-Whitman NF)	1	3
Western juniper	4	2	4	4
Engelmann spruce	2	3	2	4

1 = **Highly susceptible**; principle host and severely damaged
2 = **Intermediately susceptible**: occasional host and moderately damaged
3 = **Tolerant**: infrequent host with minor damage
4 = **Resistant or Immune**: rarely infected or immune

Table 3. Proportion of conifers (by basal area) with confirmed root disease by species in sampled stands on the Wallowa-Whitman National Forest, Oregon, by stand type (plant association) and management history classes in 1986 and 1987 (Schmitt *et al.* 1991)[1].

Root Disease

Stand Type[2]	Laminated root rot	Armillaria root disease	Annosus root disease	Blackstain root disease	tomentosus root and butt rot	Schweinitzii root and butt rot
Unentered[3] Pine	-	0.034	0.005	-	-	0.009
Managed[4] Pine	-	0.011	0.012	0.001	-	0.009
Unentered Wet Fir	-	0.025	0.013	-	0.006	0.003
Managed Wet Fir	0.0004	0.026	0.053	-	0.007	0.009
Unentered Dry Fir	-	0.016	0.018	-	0.002	0.01
Managed Dry Fir	-	0.029	0.03	-	0.005	0.01

[1] Includes dead and live-infected trees

[2]Pine Strata include stands currently having, or once having a ponderosa pine component (>10%) and a true fir component

Wet Fir Strata includes true fir stands without a Douglas-fir component and presence of spruce or other wet site indicator plant species

Dry Fir Strata includes true fir stands with a Douglas-fir component or dry site indicator plant species

[3]Unentered stands with no timber harvest/cutting/thinning history

[4]Managed stands having had at least one partial removal entry

Current levels of root disease in the Blue Mountains can be estimated from several data sets. Plot data from the Region 6 Inventory and Monitoring System Current Vegetation Survey (CVS) covers the Wallowa-Whitman, Malheur, and Umatilla National Forests. Data was collected in recent years by stand examiners that received training in identifying root diseases. Data is summarized in Table 4.

Table 4. 1993 CVS plot root disease occurrences on the Malheur, Wallowa-Whitman, and Umatilla National Forests, by proportion of trees infected.

	Root Disease					
Host species	general or unidentified	annosus root disease	Armillaria root disease	laminated root rot	blackstain root disease	**total**
ponderosa pine	0.0014	0	0.0001	0	0	0.0015
grand fir	0.0094	0.0001	0.0023	0.0008	0.000013	0.0126
Douglas-fir	0.0093	0.0003	0.0008	0.0005	0	0.0109
western larch	0.0049	0	0.0005	0.0001	0	0.0054
subalpine fir	0.0078	0.000035	0.0029	0.0004	0	0.0112
lodgepole pine	0.0019	0	0.0001	0.0001	0	0.002
Engelmann spruce	0.0138	0.0002	0.0003	0.0008	0	0.0151
whitebark pine	0	0	0.001	0	0	0.001

This data is from the best available permanent plot information. Based on recent informal surveys and the survey reported by Schmitt and others (1991), It is highly likely that these data substantially underrepresents the incidence of root diseases on all three Blue Mountains National Forests. This is to be expected, as root diseases are often difficult to recognize, especially in stands having substantial defoliator damage, as western spruce budworm (*Choristoneura occidentalis*) defoliation was severe through nearly all the Blue Mountains mixed conifer type when the plots were last read.

RISK RATING

Several methodologies have been developed and described in recent years on risk rating Northwest conifer communities for root disease at the stand- to watershed-scale level. Williams and Marsden (1982) identified several host and site characteristics that they used to predict root disease center frequency. Hessburg *et al.* (1999) developed a stand- and landscape-level risk rating methodology for a number of forest insects and diseases that included a collective rating for root diseases. For root diseases they used: site quality, host abundance, canopy structure, host age, and host type continuity to score stand polygons, and three hazard levels were assigned on the basis of total score values. Photo interpretation of both historic and recent aerial photographs were used for the model parameters, and hazard was determined to estimate changes in incidence of various insects and diseases from the early 1900's to the present. Schmitt and Powell (2001) have recently modified this system for current aerial photo-interpreted data on the Umatilla National Forest.

UPEST insect and disease risk calculator (Scott *et al.* 1998) has been used for several years in the Watershed Analysis process on both the Umatilla and Wallowa-Whitman National Forests to risk rate watersheds stand polygon level for 15 insects and diseases, including mixed conifer root diseases (annosus root disease, laminated root rot, and armillaria root disease, collectively), schweinitzii root and butt rot, and tomentosus root disease. Input data can come from several source types including stand examination and interpreted satellite imagery. Risks for root diseases are determined by stand parameters including plant community series, existing vegetation, stand structure, successional stage, and disturbance history.

Steele *et al.* (1996) designed a hazard rating system that includes a number of insects and diseases, including: annosus root disease, armillaria root disease, and schweinitzii root and butt rot. Data requirements include information collected in a field visit (stump count, wounds, fruiting bodies, etc.), as well as information which can be retrieved from stand exam databases.

Stand Succession Modeling

The Vegetation Dynamics Development Tool (VDDT) was developed to project changes in vegetation structure and composition over time with the influence of a variety of disturbance agents acting on natural stand succession (Beukema and Kurz 1998). Stand structure and disturbance event projections are currently being modeled using VDDT on the Umatilla and Wallowa-Whitman National Forests portions of the Blue Mountains Demonstration Area. A variety of disturbance agents, including fire and insects and diseases, management, and their interactions, are used to adjust probability functions of vegetation succession into the future. For example, the proportion of a watershed in each structural stage, such as *stand initiation, stem exclusion, and young multi-story*, can be projected into the future given the effects of management, fire, and various biotic agents, such as root diseases. Use of this technology is expected to at least partially replace the traditional growth and yield projection methodology in the forthcoming Forest Planning process.

Growth and Yield Modeling

The Forest Vegetation Simulator (FVS) previously known as the Prognosis Model (Stage 1973; Wykoff *et al.* 1982), is series of locally-calibrated growth and yield models with a variety of management options, and several insect and disease model extensions. The Blue Mountain Variant of FVS includes the Western Root Disease Model extension (Stage *et al.* 1990). Using either tree and stump data from plot tree records, or root disease pocket information, FVS will model the effects of root disease on forest production as well as estimate the spread and area infected by root disease over time.

Key to the Common Conifer Root Diseases in the Blue Mountains and Associated and Similar Appearing Causes of Mortality.

1.a Bark beetle attacks are evident by the presence of boring frass on the bark surface and/or egg and larval galleries are observed where bark is removed..2

1.b Tree death or decline is noted without apparent primary bark beetle activity. Mortality is in groups or expressed as scattered dead single trees. Mortality in centers has occurred over a span of more than two or three years..3

1.c Tree death primarily due to lower stem breakage of living trees associated with decay in the butt. Primarily western larch, Douglas-fir, and Engelmann spruce, but other conifers as well..7

2.a Bark beetles are usually associated with predisposing agents, including root disease. Trees have been killed over a number of years, usually in a pattern of an expanding pocket; look closely at the roots or recently-killed or live infected trees, and **confirm** decay, mycelial growth, and other symptoms of root disease..3

2.b Bark beetle activity appears independent of root disease. Most trees have been killed over a short time span (2-3 years), dead trees remain standing for at least 8 to 10 years. No trees having gradually declining crowns. No obvious root decay or mycelial growth on recently-killed trees...BARK BEETLES

3.a Dead trees are mostly standing and little evidence of root decay or damage can be found, or trees have been dead for at least 8 to 10 years before they topple. Lodgepole and second-growth ponderosa pine may have rotted roots after being dead for at least 10 years, and bark beetle galleries are evident 4

3.b Trees are mostly down and have reasonably solid root systems. Trees are mostly oriented in a single direction. Trees appear to have gone over about the same time as judged from foliage, branch and bark deterioration ....WINDTHROW

3.c Trees both standing and down. Mortality has obviously been occurring over a number of years as indicated by evidence of expanding centers and different stages of deterioration of dead trees. Some live standing trees that are adjacent to mortality have signs of crown decline..5

4.a Host is ponderosa pine and chocolate- to black-stained wood is found in the outer sapwood at the root collar of declining or recently-killed trees. Common on the southern Malheur NF ....BLACKSTAIN ROOT DISEASE

4.b Root diseases and associated decay is not evident. The state of deterioration suggests that trees were all killed over a 1- to 3-year time frame...BARK BEETLES

5.a Trees are mostly standing until they have been dead for at least 5 years. Some trees break mid-bole. Close examination of decay indicates a yellow rot with numerous black zone lines. Recently-killed and declining trees may have resin oozing through the bark at the root collar. Removing the bark at the root collar or roots will expose robust cream-colored mycelial felts...ARMILLARIA ROOT DISEASE

5.b Some trees still having green foliage will topple, exposing advanced decay on the roots. Some trees die standing but fall within a few years, also exposing advanced decay. Decay is laminated. Exterior of roots of live declining trees may have tawny-brown to buff-colored growth (ectotrophic mycelium) on the exterior..6

6.a Laminated decay is pitted on both sides of delaminated sheets. Cinnamon-colored fuzzy setal hyphae may be found between delaminated sheets of wood, between the bark plates, on broken root stubs, etc..................................LAMINATED ROOT ROT

6.b Laminated decay is pitted on only one side of delaminated sheets, or pitting is much more pronounced on one side than the other. Setal hyphae is not evident. Mortality is often in close proximity to old stumps. Surface of roots may have small buff-colored pustules scattered on the surface. Decay dug from below the soil line that is wet will be a bleached spongy white rot with scattered black flecks. ....ANNOSUS ROOT DISEASE

7.a Host is usually western larch or Douglas-fir but also includes occasional pines. Swelling in the lower butt maybe evident. Breakage exposes a red-brown cubical decay in the heartwood of affected trees...................................SCHWEINITZII ROOT AND BUTTROT

7.b Host is Engelmann spruce and exposed decay is a light-colored honeycomb rot...TOMENTOSUS ROOT AND BUTTROT

LAMINATED ROOT ROT (Also known as Phellinus root disease, Poria root rot, yellow ring rot)

Laminated root rot is caused by the fungal pathogen, *Phellinus weirii*. Prevalence of this root disease is localized in a few portions of the Blue Mountains Province. The proportion of locally infected stands is less than some other regions in the Inland West. Most commonly occurring in the northern part of the Umatilla NF and near Mt. Emily

(UMA, WAW), Kuhn Ridge, Ladd Canyon (WAW), but also occasionally found on the Heppner (UMA), Baker (WAW), and the Fox Creek and Long Creek Mountain areas on the Blue Mountain (MAL) Ranger Districts. Damage in affected stands is usually severe, with a large proportion of the susceptible stand component dead or dying within diseased potions of stands.

Hosts
While all conifers can be affected, Douglas-fir and true firs, especially grand and white firs (*Abies sp.*), are most severely affected, while other conifers are less likely to be infected or directly killed. Douglas-fir, grand and white firs are highly susceptible (readily infected and killed); western larch, subalpine fir, and Engelmann spruce are intermediately susceptible (often infected but rarely killed); and pines and juniper are tolerant or resistant (seldom infected and almost never killed). Hardwoods are immune. The most common management strategy to minimize long-term impacts involves species manipulation, where pines and western larch are preferred conifers to stock sites having laminated root rot. The pines are seldom damaged. Western larch will often develop some minor butt decay but will not be killed unless they are retained beyond 180 years, in which case they may eventually topple due to breakage in the lower butt or root decay.

Recognition
Laminated root rot usually occurs in discrete pockets or groups of trees. Stands with a high proportion of highly susceptible species can have very recognizable centers, while disease centers in stands having numerous less susceptible larch and/or pines will be less recognizable. Disease pockets are characterized as having oldest mortality near the center and more recently-killed and live-symptomatic trees around the perimeter of openings. Laminated root rot kills trees by actively decaying the roots, as well as killing the cambium, so trees will topple while still alive or soon after death, exposing advanced decay in the root system.

Disease centers may be first recognized as understocked portions of conifer stands, often with hardwoods and brush established due to gaps in the overstory canopy (Figure 1). There will usually be evidence of mortality and downed hosts, sometimes accompanied by timber salvage or fuelwood cutting if near roads (Figure 2). Residual susceptible hosts within and on the perimeter of centers may have crown symptoms that include: reduced terminal growth, reduced foliage retention, chlorotic or faded foliage (Figure 3), and sometimes an abnormally abundant cone crop. Root disease is will advanced before it is noticeable. Trees will not even begin to express these crown symptoms until at least 75 percent of the root system is affected. This also means that the center perimeter is further advanced than can be identified by tree crowns. Wood delaminates on the annual rings with "canoe-shaped" pits roughly 1x2 mm on both sides of delaminated sheets (Figure 4). Reddish-brown setal hyphae is usually apparent on the surface and between the delaminated sheets of decayed wood. A fairly distinctive reddish stain or decay can usually be found on stump surfaces of recently-cut infected trees (Figure 5).
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Figure 1. The presence of brush and hardwoods in conifer stands often characterize root disease centers.

Figure 2. Fuelwood harvest characterizes root disease centers near roads.

Figure 3. Typical root disease crown symptoms of thin, chlorotic foliage. These Douglas-fir are infected with *Phellinus weirii*.

Figure 4. Laminated decay characteristic of laminated root rot. Pitting on both sides of sheets and red-brown setal hyphae are diagnostic.

Figure 5. Red crescent-shaped stain and decay on a freshly-cut Douglas-fir stump, characteristic of *Phellinus weirii.*

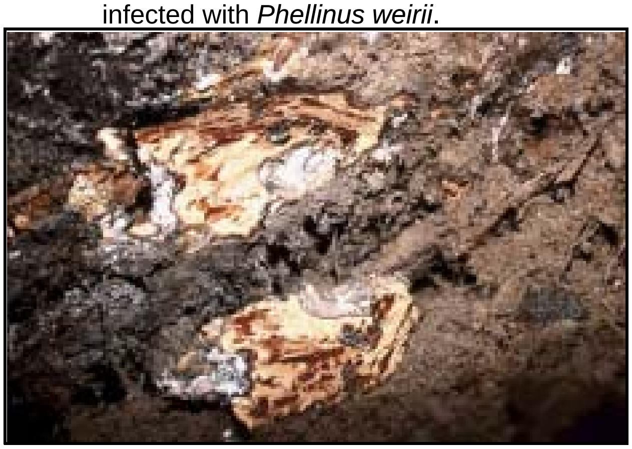

Figure 6. Ectotrophic mycelium and setal hyphae of *Phellinus weirii* on the root collar of a Douglas-fir.

On the exterior of infected roots and near the root collar of young live-infected or recently-killed trees, grayish-white "ectotrophic mycelium" usually occurs. On older trees, ectotrophic mycelium and setal hyphae are often found in the bark crevices of the root collar (Figure 6). Fruiting bodies are seldom found in the dry communities characteristic of the Blue Mountain Province, but may be located in moist areas. Where they do occur, fruiting bodies are typically crusty pore-covered growths most likely occurring on the underside of root systems, root collar, or the lower butt of windthrown trees near the ground.

In the Blue Mountain Province, laminated root rot occurs in plant associations with a historical grand fir or Douglas-fir component; these are the mesic side of grand fir and Douglas-fir associations, rather than those maintained in ponderosa pine by historical frequent ground fires. It is unlikely that laminated root rot will be found in sites with Douglas-fir and species of true fir that have only become established since the suppression of ground fire, although it is probable that in time spread will occur where there are adjacent infected sites.

Tree, Stand and Community Effects

After a tree becomes infected, the root system starts dying and/or decaying along with progression of the fungus. Smaller trees will be killed relatively quickly following infection, while larger trees may take decades to die, or possibly never be killed outright, although they may eventually exhibit crown symptoms of infection, and sometimes be killed by other opportunistic agents, such as the Douglas-fir beetle (*Dendroctonus pseudotsugae*). Trees may be killed standing or topple while still having green crowns. Less susceptible hosts such as larch may develop decay in the butt although they will usually not be killed.

As the result of mortality, canopy gaps develop and brush and/or conifer regeneration will become established. Regeneration of susceptible species will result in those trees eventually being killed. Gaps that develop provide diversity in structure and vegetation. Fuel accumulation may be excessive in areas, and if a large portion of the host type is infected, reduced fiber production may become an issue. If stands are protected from fire long past the natural range of periodicity for disturbance, stocking of susceptible shade tolerant conifers will dominate, allowing maximum spread of root disease. This is how an epidemic condition develops where heavy widespread levels of inoculum in the soil will restrict available management options for maintaining healthy stocking in the future.

Disease Spread

Laminated root rot is considered a disease of the site, very infrequently colonizing new areas and seldom disappearing from sites where already established. While spore spread of *P. weirii* is rare, it is the primary mechanism for long distance dispersal of the fungus demonstrated by its current distribution. Most efficient spread is between trees via root contacts or grafts, or roots of young trees growing into infected woody material in the soil, such as roots of old stumps and the roots of susceptible residual trees. Oftentimes, following harvest, fire, or other mortality, the fungus will reside in the soil surviving as a saprophyte on roots of stumps or fire-killed trees. Decades can pass before roots of regeneration contact this woody material, but fungus (or disease) spread can still occur for up to about 35 years from *P. weirii*-infected dead roots, due to several long-term survival strategies used by the fungus. Oftentimes, regeneration will not become infected until it is about 15 to 20 years old even if growing within an active root disease center, due to time required for roots to contact *P. weirii*-infected material. The ability of *P. weirii* to persist for long periods as a saprophyte allow it to remain on sites in perpetuity as long as even a few susceptible conifers are in the stand. Disease activity will rise and fall with the successional stage of the community, increasing with the prevalence of shade-tolerant and disease susceptible species, and falling with the dominance of early-successional shade intolerant larch and pines.

In stands with numerous susceptible hosts, radial enlargement of centers will average about 1 to 1.5 feet per year. Accurately determining the extent of disease centers by above-ground symptoms is nearly impossible since crown symptoms do not become noticeable until about 75 percent of the root system is colonized by the fungus. Depending upon stand type and characteristics, bounds of infection can be estimated as extending 50 feet beyond last apparent symptomatic trees on the center perimeter. Alternatively, use the "two tree space" rule; that is, include in the root disease center the next two trees or the equivalent space beyond the last symptomatic tree, as infected. Recent research on the west side of the Cascade Mountains indicates that disease centers can have a diffuse pattern of inoculum distribution, with trees being infected that are not recognized, and trees near confirmed inoculum that do not become infected (Thies and Nelson 1997). If similar patterns occur in infected Blue Mountain stands, the procedures described for marking centers may not contain all infection and some potential survivors may be removed.

Management

Laminated root rot pockets will increase in area and proportion of the stand host component infected, as long as late successional conditions occur and there is a lack of disturbance, especially fire. Resource impacts have become a concern in most root disease infected areas in the Blue Mountains Province. Reducing laminated root rot activity and impacts are most effectively done by a process of species manipulation, that is, silviculturely shifting the species composition on diseased sites toward a mix having a high proportion of least susceptible species.

Watersheds believed to have an excess of root disease and designated for cultural treatment should have an initial survey done to determine the locations of concentrations of root disease. This information can be included in the Interdisciplinary Team assessment where treatment areas are determined. A second stage survey can then be done to determine more precise locations of root disease in stands that will be treated. Treatment should include removal of all individuals in the susceptible species group (grand fir, white fir, and Douglas-fir). Other, less-susceptible species (intermediately susceptible, tolerant, resistant or immune) would be retained, and regeneration of pines and larch encouraged.

Stands with much of their area in root disease centers, either large centers or numerous coalescing centers, are most efficiently treated uniformly. However, where centers are discrete and silvicultural treatment can effectively be done differently in root disease-infected and uninfected areas, on-the-ground marking of centers of infection should be attempted. This can be modified during harvest by having tree fallers mark stumps having characteristic stain of the fungus by specifying C-Provision C6.412--Stump Marks, in the timber sale contract. Modifying designated areas of infection based on stained stumps will probably enlarge the area identified as infected over crown symptom and mortality delineation. Conifer susceptibility to *P. weirii*, is listed in Table 2. In mature stands, disease centers and buffers of at least 50 feet (as measured from the last visibly infected tree or marked stump), or inclusion of two additional tree spacings beyond symptomatic trees or marked stumps, would be converted to species that are immune (hardwoods), resistant (ponderosa pine), tolerant (lodgepole and western white pine), or intermediate in susceptibility (western larch), while susceptible firs and Douglas-firs are removed and periodically rouged out. In shelterwood/seedtree treatments, non-susceptible trees should be retained in these "areas of infection" and management of non-susceptible natural regeneration and/or supplemental planting used to enhance the stocking of non-susceptible species. Location of root disease treatment areas should be included in a permanent database so follow-up treatments are not missed, and the long-term treatment strategy documented.

Species manipulation is most easily accomplished following significant disturbance such as a regeneration harvest or fire, where conditions have been made favorable for the establishment of shade intolerant seral species. In situations where there are numerous susceptible host species in and around targeted root disease centers, effective treatment will require their removal. Where management direction does not allow removal of such trees, e.g. if they are larger than 21", treatment success will be less then complete. Incomplete treatment will likely result in infection of regeneration soon after establishment.

Thinning should be avoided in severely infected stands or stands with mostly susceptible species, but should be encouraged in stands with mostly full stocking of less than susceptible species, where removals would remove susceptible trees.

In most plant communities, use of prescribed burning that emulates historical ground fire can be used to manipulate species composition to a higher proportion of trees less susceptible to root disease. This is especially true where the objective is to remove true firs or small diameter Douglas-fir. Stand replacement fires that result in the replacement of shade tolerant species with seral pines and larch also control root disease.

Laminated root rot found within or adjacent to recreation sites and other high use areas commands immediate attention and action since tree failures are likely in these cases. Similarly, when developing new or enlarging existing recreation areas, sites should not be located near known pockets of laminated root rot due to the inherent hazard and liability.

Ineffective Management Strategies

Burning, either stand replacement fire, or cooler underburns, will not incinerate or kill *P. weirii* residing in woody material in the soil. Even very hot fires that burn out stumps and major roots do not seem to significantly reduce the subsequent infection that results if susceptible conifers promptly regenerate burned sites. However, as mentioned earlier, fire will modify species composition that may reduce disease activity in the future by killing or burning a high proportion of susceptible species and allowing regeneration of root disease tolerant seral species.

Resistance to *P. weirii* within susceptible species has not been demonstrated, thus selection and breeding programs for such a trait are apparently futile.

Stump treatments are not a viable option for reducing infection hazard. Borax treatment, which is recommended for control of *Heterobasidion annosum*, is not effective against *P. weirii.* Use of rather toxic fumigants have used to kill the fungus within root systems, but there are limited opportunities to use these operationally due to safety and environmental issues as well as the expense of such treatment.

Site fertilization has not been shown to be effective in reducing the growth of the fungus in root systems, although high levels of nitrogen may reduce the period of time *P. weirii* survives in roots. Nitrogen-fixing non-host vegetation may also serve this purpose as well as reducing the fungus population by not perpetuating infected root biomass..

Clearcutting or removal of all the hosts will not work for the short term since *P. weirii* survives for up to 35 years in root systems of stumps. However, such a treatment in conjunction with restocking of non-hosts for several decades, would be effective in reducing the potential for root disease in subsequent stands.

ARMILLARIA ROOT DISEASE (also known as Shoestring root rot)

Armillaria root disease affecting conifers in the Blue Mountain Province is caused by the fungus pathogen *Armillaria ostoyae*. Armillaria root disease found in many different areas throughout the world was once believed caused by a single pathogen, *Armillaria mellea*. Research has shown that there are actually a number of closely-related fungal species in the genera *Armillaria* that were once considered that single species. In the Blue Mountains, there are several different species of *Armillaria* which cause decay and root disease, including some that will damage hardwoods, but only *A. ostoyae,* that infects conifers, is of primary concern. Armillaria is found throughout many if not most forested communities in the Blue Mountain Province. While expression of disease is usually minor to moderate, it is fairly common to encounter very active and aggressive tree killing by this disease. Representatives of such cases can be found throughout this area, with some of the best examples of extensive root disease being: Kuhn Ridge, Wallowa Valley RD (WAW); Ladd Canyon and Mt. Emily, LaGrande RD (WAW); Hoodoo Ridge, Walla Walla RD (UMA); Overholt Creek, and the largest root disease complex in the Blue Mountains that is within portions of Reynolds and Clear Creek drainages, and Thirsty Gulch, Prairie City RD (MAL), and Unity RD, (WAW), respectively. There are several large individual mortality centers in this area including the largest known individual root disease center in the world, a confirmed single individual *A. ostoyae* genotype that covers 2800 acres (Brennan Ferguson, manuscript preparation in progress).

Armillaria ostoyae displays considerable variability in root disease virulence, some of that is believed to be the result of genetic variation, but other factors such as site disturbance, especially soil compaction, will sometimes exasperate disease activity. In northern Idaho and western Montana, disease occurrence and activity has also been shown to vary with site quality and different plant associations. McDonald (1987) has found that Armillaria disease expression is minimal in cold-dry and warm-dry communities relative to other communities. McDonald *et al.* (1987) found that there is an inverse relationship between site productivity and Armillaria pathogenicity, which is contrary to what was reported by Carlson (1989). In Douglas-fir dominated communities, McDonald (1987) found that root disease was most commonly found in those with site indices between 65 and 100', while both poor quality and high quality fir sites seldom had Armillaria. Note that Armillaria pathogenicity and occurrence are different characteristics.

Hosts

While all conifers may become infected, western larch, western white pine and lodgepole pine are most resistant in nearly all cases. Grand fir, white fir, and subalpine fir almost always are very susceptible. Douglas-fir and ponderosa pine will vary somewhat in relative susceptibility depending upon locality and site, although they usually are both quite susceptible when less than about 25 years old.

Trees that have been damaged or stressed by basal wounding or compaction of the soil in the rooting zone are more likely to become infected with *A. ostoyae*. In some cases only the individually affected tree becomes infected, in other cases, root disease will develop in these trees then spread to nearby trees. Morrison *et al.* (2001) found that selectively harvested stands having endemic levels of Armillaria had a significantly higher incidence of Armillaria root disease associated with increased inoculum potential. As live-infected trees are cut, the fungus rapidly expands from quiescent lesions, fully colonizing the entire root system, and spreading the disease to adjacent trees. Trees in disturbed sites also had more lesions.

Trees that are planted, even those of relatively resistant species, are more apt to become infected than naturally established trees. Sometimes this is at least partially due to seed being acquired far enough away or at a different elevation, so that the stock is not adapted closely enough to the site. Additionally, even trees that are planted correctly will not develop as healthy a root system as that of a tree that has naturally established. There often will be some level of twisting of the root system or similar malady that results in stress, thus a higher proportion of planted trees will become infected and killed relative to naturally regenerated stock. Less than ideal planting techniques only exasperate the problem. For these reasons, it is highly desirable to use, wherever available, natural regeneration of the most site adapted and least Armillaria-susceptible species to restock diseased sites.

Recognition

Armillaria root disease can occur in distinct centers in all ages of forested communities, or as scattered individual or small groups of affected trees (Figure 7). Highest rates of mortality occur to younger trees, although they will continue to succumb as trees and stands mature. Since trees are killed by cambial girdling of the roots and root collar, and wood decay does not usually become extensive in the root system until after the tree is killed, trees usually die standing and topple years later. Older trees may be infected for 2 or more decades before they are eventually killed, if ever. Such trees may display characteristic crown symptoms that can include: rounded tops, chlorotic foliage with shortened needles, and only a year or two of needle retention. Younger sapling-size trees may be killed in only a year or two following infection. These trees may show reduced height growth for the previous year or two as well as obvious foliage symptoms.

Upon close examination of recently-killed or live infected trees, Armillaria is usually easy to identify. Pitch flow or basal resinosis at the root collar is not as dramatic as what occurs in wetter climates, but is usually recognizable in Blue Mountain communities (Figure 8). Using a hand ax or knife, removing a section of bark at the root collar at or below the soil line on infected trees, especially those with basal resinosis, should expose creamy-white fan-shaped mycelial felts of the fungus (Figure 9). Often the texture of latex rubber sheets, these are usually found on recently-killed trees or those showing crown symptoms. Nearby infected trees can be identified by exposing felts on primary roots. Since the mycelial felt replaces the cambium, roots with felts are dead or close to it. Trees that have been dead for 5 years or more may no longer have recognizable felts at the root collar, however after felts have deteriorated, fan-like impressions on the inner bark can be seen, or residual felts may be still found on well buried roots. Black rhizomorphs may be found under the back and often on the outside of roots (Figure 10). Often rhizomorphs can be found on the surface of healthy roots, on windthrown trees for example, not having any expression of root disease, probably because a species of Armillaria is in the soil, but it may not be pathogenic. Less reliable means of diagnosis include the recognition of the characteristic decay caused by *A. ostoyae.* Incipient decay is light yellow sometimes with a water-soaked appearance. More advanced decay is light colored yellow-brown usually with abundant fine black zone lines. As decay advances, the wood will become stringy, then spongy, often soaked with moisture.

For a period in the late summer and fall, often after a substantial rain, mushrooms may develop around the base of diseased trees and above infected roots (Figure 11). Because of the short time they are found, these are not reliable means of identification.

Tree, Stand, and Community Effects

Armillaria results in growth loss over a number of years on infected larger trees and will usually eventually cause mortality. Centers initially result in the development of understocked portions of stands and depending on the plant community type and the size of openings, shade tolerant (root disease-susceptible) or shade intolerant (root disease resistant) species become established. As with laminated root rot, heavy regeneration of root disease-susceptible hosts will maximize the spread, inoculum load, and resultant disease activity into the future. An unhealthy epidemic stand condition, where heavy widespread levels of inoculum are in the soil, will restrict available options for future management.

Numerous snags are continually being created that may remain standing for as long as a decade, and even longer for large trees, but dead trees eventually fall. Mosaics of heavy loads of down woody material develop and present an ever-increasing risk to stand-replacement fire.

Bark beetle activity almost always associated with root disease. Root disease-infested stands will help maintain a higher than normal resident population of insects. Disease-weakened trees will be usually be attacked by beetles, and the combination of agents being very effective in causing mortality. Douglas-fir beetles in firs, and fir engravers (*Scolytus ventralis*) in true firs, mountain pine beetles (*Dendroctonus ponderosae*), Ips beetles (*Ips sp.*) in pines and western pine beetles (*D. brevicomis*) in ponderosa pine, can all be expected.

Disease Spread

A. ostoyae maintains itself as a saprophyte for up to 35 years, and perhaps longer, in stumps and root systems of dead trees, although the fungus will remain viable on or near the surface of roots for somewhat less than that. Roots of susceptible trees that contact these dead roots or the infected roots of live-infected trees may become infected if the fungus mycelium grows across those contacts or grafts. Additionally, rhizomorphs are able grow through soil for several feet from diseased roots and may introduce the fungus if they contact the roots of susceptible trees, although they do not have the infectability potential of diseased roots. While such below ground growth of *A. ostoyae* is believed quite common, the fungus must overcome host resistance to actually become successfully established in the root system. The aggressiveness of the fungal pathogen, inoculum load in the soil, and the susceptibility of the host related to species and stress, are probably the main factors in resultant levels of infection.

A. ostoyae is a relatively unaggressive saprophyte and seldom is able to out-compete a number of other fungi and successfully colonize stumps or root systems of trees killed by other agents. However if *A. ostoyae* is already established on one or more roots on infected lesions, it can quickly spread throughout the remaining root system as soon as the tree is killed (or tree cut). Spread of the fungus is maximized by partial cutting. In lightly- to moderately-infected stands, A. ostoyae will quickly fully colonize stumps that had some level of infection, and these newly-infected stumps have the highest inoculum potential, or the ability to result in spread of the disease (Morrison *et al.* 2001). Inoculum potential diminishes dramatically after viable mycelium no longer occurs near the surface of roots. Where there are a high proportion of host species in a well-stocked conifer community, The fungus can spread from the newly colonized stumps to adjacent residual host trees resulting in rather high infection. Infection levels and subsequent root disease and mortality is largely a function of the virulence of the particular strain of the fungus, the susceptibility of the hosts and a variety of soil characteristics. Some spore dispersal of *A. ostoyae* is probable but is not considered a significant cause of spread.

Management

Management strategies for ongoing large virulent Armillaria root diseased areas are dependent upon the ability to use rather large-scale restorative treatments. Unfortunately, there are a number of large root disease hotspots in the Blue Mountains, most of which are believed to have become substantially more active in the last few decades. Preventing such situations from initially developing involves avoiding exasperating actions as well as actively managing against conditions that predispose trees and stands to root disease. Prevention strategies are much more effective than attempting to suppress epidemics. Effective long-term prevention strategies are especially critical in or near areas with known aggressive Armillaria root disease.

Management strategies and techniques that minimize the potential for conditions favoring development of excessive Armillaria includes: cultural activities that maintain seral species dominance in communities that normally succeed to shade-tolerant species in the absence of ground fire; use of seral species natural regeneration to re-stock sites, or carefully selected planting stock to regenerate sites requiring artificial reforestation; and the use of logging and slash disposal techniques that minimize soil disturbance.

Soil ripping has been done on compacted sites, especially skid trails, to improve soil bulk density. The effectiveness of this treatment with regard to subsequent Armillaria activity is not known.

Ground fire, once frequent on all but the most mesic communities in the Blue Mountains, had substantial influences on succession, composition, structure and density of vegetation. Probably the greatest effects of these fires were on the community dominance of fire-tolerant species, and secondly, wide spacing between large trees that maintained tree vigor by the perpetual maintenance of associated low stocking levels. Drought resilience of vegetation was a direct effect of such stand structure. Fire also has been found to modify the soil fungal community, probably through changes in soil chemistry. Fungi of the genera *Trichoderma sp.*, that compete with, and are antagonistic to *Armillaria ostoyae*, have been found to become more common in recently-burned soils (Reaves et al. 1990). With the long-held policy of suppressing all fires, vegetation and site conditions have changed substantially since the late 1800's and allowed Armillaria root disease activity to intensify.

Stands that are currently being impacted by excessive Armillaria root disease should be given a high treatment priority to reduce future losses. There are a range of options in treating these infestations depending upon the level of disturbance allowed and other resource concerns. Initial surveys are recommended, especially at the watershed planning level. Risk rating, such as that done with UPEST (Scott *et al.* 1998) can be used to identify stands having a high likelihood of hosting infestations. Armillaria root disease centers are sometimes clearly visible on resource aerial photographs in some Blue Mountains plant community types. Ground surveys, including transects or stand exams done by crews trained in identifying root diseases, are most likely to supply quality information. These data should be incorporated into the environmental analysis for vegetation management projects and the identification and prioritization of treatment areas.

Stand level analysis is most effectively done following broad-scale surveys. Mapping of root disease centers might be considered where root diseases are known to cover only a portion of the proposed treatment unit and there is stocking of disease-susceptible species that need to be retained, such as wildlife screening cover, for example. In such cases there will be differences in the silvicultural prescription based on location of root disease. Different treatments need to be marked on the ground with locations kept in a GIS database. Following on-the-ground delineation of root disease centers:

1. Mark for removal all trees (precommercial size also) of highly susceptible species that are within root disease centers and a buffer of 2 normal tree

Figure 7. Group and scattered tree mortality caused by Armillaria root disease.

Figure 8. Abundant basal resin flow is characteristic of trees infected with *Armillaria ostoyae*. On this tree infection has progressed to the root collar and above.

Figure 9. Distinctive cream-colored, fan-shaped mycelial felts of *Armillaria ostoyae* are found under the bark of infected trees.

Figure 10. Black rhizomorphs of *A.ostoyae* are found on the exterior of roots and sometimes under the bark of infected trees.

Figure 11. *Armillaria ostoyae* mushrooms may be found around the base of live-infected or recently killed trees after rains in the late summer and fall.

spacings beyond last dead or symptomatic trees on the perimeter. In many cases these will qualify as group selection removals.

2. Areas outside of centers and buffers can include a leave component of susceptible species.

3. Prepare the site for regeneration of a mix of most resistant species adapted to the plant community. Use of natural regeneration is preferable.

It is imperative that areas outside of disease centers and buffers be carefully treated using preventative strategies for Armillaria, to avoid the development of root disease. In most situations, treatment units will be treated homogeneously and there is no need to mark locations of root disease centers on the ground. Thus, entire units should be treated with a similar treatment to reduce current root disease as well as risk to future disease activity. Such stands may have a high incidence of scattered root disease, the entire block may be a large center, or a general reduction in shade tolerant host composition is desired.

Other control methods including inoculum removal (stump pushing) and use of chemical fumigants have been tested and are effective in certain situations, but are usually not considered except in unusually valuable stands or where there are no alternative species options.

Ineffective Management Strategies

Stump treatment is not effective for *Armillaria ostoyae*, since spread by spores is incidental. Most infection occurs within the soil profile as the causal fungus moves across root contacts.

Fire has been mentioned and should be considered a mechanism that contributes toward prevention by maintaining a beneficial soil fungal population, and more importantly, restoring historical conifer species composition, but it is not a control strategy. Fire is not effective in reducing inoculum in the soil or significantly reducing its infection potential. Even in cases where stumps burn out, infection still occurs years later when roots of regeneration contact remnants of roots buried in the soil.

Thinning has been proposed by some and condemned by others. There are no clear trends that have been observed in the Blue Mountains. Commercial thinning or partial removal harvests, are supported by many as the trend of the future to replace regeneration harvest systems. This will undoubtably exasperate the incidence of root disease, both by subjecting residuals to damage and disturbance and by perpetuating a condition that limits the ability of seral species to become established. Precommercial thinning has a number of benefits that outweigh any additional impact Armillaria may have if any. In stands with a mix of species, thinning to increase the proportion of seral disease resistant species is probably beneficial. The effects of increased vigor due to reductions in stocking have not been shown to be significant, but as previously mentioned, precommerical thinning can be used to meet silviculture objectives early, avoiding the need for commercial thinning and the associated disturbances to the site and residual trees.

ANNOSUS ROOT DISEASE (also known as Fomes root and butt rot)

Annosus root disease is caused by the fungus *Heterobasidion annosum*, previously known as *Fomes annosus* and briefly as *Fomitopsis annosa*. There are actually two varieties of *H. annosum* that occur in the Blue Mountains; the S-Type annosus infects true firs throughout most all of the various mixed conifer types, and the P-Type annosus infects ponderosa pine and is most common on the marginal productivity sites in the pine community series in the southern Blue Mountains. Many of these types of stands have had heavy removals of large pine for most of this century. Most annosus root disease in pine communities occurs as scattered small openings or mortality pockets centered around large old *H. annosum*-infected pine stumps (Figure 12).

Annosus in true fir can be found in most mixed conifer stands, both with a component of either grand fir or white fir, and high elevation stands containing subalpine fir. Usually incidence is relatively low unless there have been multiple partial removal entries and numerous large true fir were removed. Many of these mixed conifer stands have had partial removal entries where more valuable pine, larch and Douglas-fir were harvested, with little true fir removal, or fir were only recently cut,and root disease has not yet become apparent. Such stands usually don't have much more than normal background levels of annosus root disease. However, harvest entries in the last several decades usually included the removal of large true fir. In cases where there were multiple entries, and substantial amounts of large fir were removed, root disease activity can be profound.

Hosts

All conifers can become infected with one or both strains of *H. annosum*, but in this area, significant damage is only observed in true firs and ponderosa pine. Other conifers are very infrequently infected and usually at low background levels. Douglas-fir *H. annosum* infection and mortality has been confirmed in several areas on the eastern extent of its range on the Pine Ranger District, Wallowa-Whitman National Forest. Further eastward, in southern Idaho, Douglas-fir becomes a much more common host. In the Blue Mountains, most damage occurs on the wet grand fir series Plant Associations that naturally support a significant fir component throughout normal plant succession. Annosus is becoming more common on dryer grand fir series sites that were maintained in near-pure ponderosa pine by frequent ground fire, but in recent years, grand fir have become established in these stands with the absence of light ground fire. Subsequent removals of some of these fir, especially the larger individuals, has resulted in large colonized stumps which serve as infection foci for residual fir on the site. Annosus root disease is expected to become much more common in these types of stands in the future, especially where stump treatments were not used.

Those sites in the ponderosa pine communities which are near-pure pine due to southerly exposure and lack of available soil moisture usually offer the best examples of mortality caused by annosus root disease. Most of these sites have a long history of multiple selective harvesting, resulting in numerous large stumps. There is evidence that *H. annosum* does occur in a much wider range of pine sites, but recognizable damage to the tree infrequently results. Apparently, numerous trees on many pine sites may have a few *annosus*-killed dead and decayed roots but the disease does not reach the root collar or colonize more than a small portion of the root system. Stress induced by poor site quality or applied to the host by other agents or site factors are needed for the fungus to overcome host resistance and result in appreciable damage. For example, there are examples of offsite planting stock developing severe annosus disease on sites where natural regeneration is not damaged. Similarly, good quality pine communities can be significantly damaged by annosus root disease were soil compaction was severe.

Recognition

Annosus root disease is usually more difficult to identify than other Blue Mountains root diseases, primarily because good examples of signs and symptoms are often lacking. Oftentimes, only a probable diagnosis is made, and that by eliminating other possible root diseases as the causal agents in obvious root disease centers. Under ideal situations, most or all of the following signs can be observed, although most often only a few are. As with other root diseases, crown symptoms can usually be observed. Thinning crowns and reduced height growth are especially visible in grand and white firs and ponderosa pine with advanced root disease that have more than 75 percent of the root system killed, but bark beetles may attack trees before crown symptoms are obvious, especially on larger trees. Dead trees and windthrow in distinct pockets, or at least groups of several dead as well as symptomatic trees, are indicative of a root disease infestation. Best examples of wood decay can be seen by close examination of the root systems of windthrown trees (Figure 13). Annosus root disease has a range of decay forms, some of which are quite characteristic. Initially, incipient decay may be observed as a wine-red stain in the interior of roots with a characteristic irregular outline. After decay has started to break down the structural integrity of the wood, delamination occurs on the annual growth rings and pitting will usually be obvious on only one side of delaminated sheets. As with the stain, decay usually has an irregular outer margin (Figure 14). Advanced decay from deep in the interior of stumps, or from roots/root collar excavated from below the soil line, is most apt to be characterized as being a wet spongy white rot with scattered black flecks. Loose laminated sheets are more typical of dryer advanced decay that is above-ground and exposed (Figure 15).

Characteristic fruiting bodies or conks are found in the interior of large (>18"diameter) stumps that are at least 20 years and not more than about 35 or so years old, and are probably the most diagnostic sign of the fungus. The stumps and root systems will likely be fully-colonized by *H. annosum* before conks are ever produced. Conks can be found by peering into the hollows of such stumps, or breaking stumps apart that are fairly well decayed (Figure 16). The presence of conks in stumps does not mean there will be root disease found, it simply means that inoculum is on the site. In many situations, especially in good quality pine sites, noticeable mortality is not apparent, although some root infection may be occurring. Similarly, conks do not need to be found to have a root disease situation. Stumps can be completely colonized by *H. annosum* without having conks produced, although examples of *H. annosum* decay should be present. Where root disease is occurring, large stumps with annosus decay or conks will usually be in the center of pockets of mortality (Figure 12).

On symptomatic or recently-killed trees, especially pines, checking just below the duff layer around the base of the bole may reveal small popcorn-shaped fruiting bodies of *H. annosum*, that confirm the presence of annosus root disease. On roots of smaller trees that can be pulled from the ground, or on excavated roots of larger trees, small buff-colored pustule-like conk primordia are often found along the outer surface (Figure 17) of infected trees. These are distinctive, and when numerous, they also confirm infection.

There are several other indicators of annosus root disease that may be observed, although these are not as positive indicators of *H. annosum* infection as those signs previously mentioned. Among these are dead resin-soaked roots, especially in pine. Recently-killed roots and root collar tissue will have the bark loosen and there is often a characteristic mottled pattern visible on the inside of the bark and the exterior of the xylem. Additionally, there may be some visible ectotrophic mycelium on the exterior of infected roots and at the root collar.

Tree, Stand, and Community Effects
In both the true fir and ponderosa pine community types, annosus root disease is usually restricted to relatively small centers that are often scattered throughout stands. Slaughter and Parmeter (1995) found that most centers they studied in California were relatively small, having an average diameter of 46 feet, and being restricted to the rooting zone of the original infected stump. Less commonly, some investigated centers expanded beyond the rooting zone of the infected stump and spread tree to tree. These centers averaged about 88 feet in diameter. Annual spread rates were rather limited, averaging less than 0.7 feet/year for the smaller centers, and 1.3 feet/year for the larger centers.

Root disease centers contribute to diversifying stand structure and breaking up the canopy in more densely stocked stands. They also contribute to high fuel loading in some types of stands that once burned rather frequently. The natural range of variability of this disease included rather low levels of incidence in rather restricted plant community types. Movement of this disease into plant communities at the dry end of the grand fir series, once dominated by pine, is a good example of incidence expanding outside the HRV.

As with other root diseases, infected trees may be killed by bark beetles after they are sufficiently weakened by damage to their root system. True firs are usually attacked by fir engraver beetles, and ponderosa pine are attacked by western and mountain pine beetles and engraver beetles (*Ips sp*.). Active root disease centers serve to maintain perpetual populations of these insects on site.

Wounded trees will often become infected with *H. annosum* and associated decay. Generally, the larger the wound and exposed sapwood, and the time since damage, the greater the extent of decay. Basal decay will result in increased levels of tree failure. As a result of basal decay, such trees may offer cover and serve as habitat for wildlife, especially mammals. Of course, after they topple, such trees also contribute toward down woody material. Less often, trees will break higher on the bole as a result of *H. annosum* infection and decay. Such snags also serve for a variety of wildlife uses.

Disease Spread
Annosus root disease can spread both by spores and by root contacts within stands after the root disease has become established. Freshly-cut stump surfaces, wounds, or stubs of wind-snapped trees serve as sites of infection. Most effective colonization that

results in disease center formation appears to be by stumps. There is a high incidence of *H. annosum* spores in the air. Spores disperse aerially for many miles during favorable conditions of high relative humidity and cool to moderate temperatures. Additional spore production because of prevalent conks in stumps of managed stands may increase infection potential, but even natural spore levels are believed to provide more than adequate infection where there are susceptible infection courts. Soon after a wound is created or a fresh stump exposed, a variety of fungi compete to colonize the tissue surface. *H. annosum* oftentimes effectively out competes other fungi and eventually colonizes the stump as well as the entire root system. Rates of colonization of true fir stumps has been found to be at least 89 percent (Filip et al 1992), but much lower in ponderosa pine; usually less than 15% (Russell *et al.* 1973) in one study, and up to 50% in another (Kliejunas 1986).

Once *H. annosum* becomes established in stumps, it can spread across root contacts to those of adjacent susceptible trees of the same species. Most disease centers expand only to about the diameter of the initial infected stump rooting zone, while some will continue to spread from tree to tree (Slaughter and Parmeter 1995). It is likely that tree defense mechanisms prevent the fungus from infecting some trees and causing appreciable damage in most cases, especially in ponderosa pine communities. Where certain conditions exist that favor the fungus over the host, the disease develops. Since true firs have a higher incidence of annosus root disease over a broader range of sites than pine, it is probable that the disease occurs more frequently due to higher levels of stump infection, more effective spread from roots of stumps to trees, or a combination of both. There are significant differences in annosus root disease center development from different size stumps. Big stumps result in larger centers because of the more extensive rooting zone. Smaller stumps, especially those of ponderosa pine on warm dry sites, may reach temperatures lethal to *H. annosum* in the summer months. Subalpine fir stumps as small as about 8" diameter can become colonized and infect adjacent fir, while ponderosa pine, grand and white fir stumps generally need to be large; at least 18" diameter, to serve as effective disease center foci. The time lag between harvest and initial onset of adjacent mortality is often substantial. Evidently, the time required for stump root colonization, spread across root systems and disease being manifested in adjacent trees, is on the order of about 20 years.

Trees infected through wounds usually do not develop root disease. Decay is contained in the cylinder of wood present at the time the tree was wounded. Tissue grown after this time (outside of the cylinder) is not invaded by the fungus, a concept known as compartmentalization.

Management

Annosus root disease incidence and severity have increased substantially with harvesting in some forest community types. There are several management strategies available to reduce the incidence of annosus root disease to more natural endemic levels.

Ponderosa pine

Ponderosa pine communities throughout most of the Blue Mountains have a relatively low level of root disease occurrence associated with stumps and harvests made this previous century. Unless significant site disturbances have recently occurred, and annosus has not surfaced as a problem in the past, root disease probably will not develop in the future. On those sites where annosus has caused mortality in the past; especially those poor quality sites, borax stump treatment should be done on any pine cut having a breast height of 12" or larger; corresponding to a stump diameter of 14" or larger. Properly labeled and registered granular borax (sodium tetraborate decahydrate) applied as a "light salting" at a rate of 1 pound per 50 square feet of stump surface, Will prevent *H. annosum* from colonizing freshly cut-stumps. C-Provision C6.412 (Option 2) can be specified in timber sale contracts to require purchasers to treat stumps soon after falling. Small stumps resulting from precommercial thinning have not been found to introduce significant amounts of infection. Also, stumps that result by removal of invading grand fir and Douglas-fir in pine communities need not be treated as they apparently pose little threat to pine. This treatment prevents new infections from occurring and will not sanitize stumps already colonized with *H. annosum*.

Those stands with a normal early seral component of ponderosa pine or western larch that were traditionally maintained in those species by frequent fires should be treated by periodic fir removals or fir-killing prescribed fire to help restore the historical composition and structure. There are a number of insect and other disease problems that develop in the fir component of these stands. Of most concern is the overstocking stress that will result to overstory ponderosa pine with the invasion of understory fir, and resultant bark beetle activity that can follow in the pine component.

Grand fir and white fir

Grand fir and white fir communities often will develop substantial levels of annosus root disease if intensively managed with frequent commercial partial removal or salvage entries. Intensively managed stands where a substantial true fir component will be maintained to maturity, as well as in subsequent generations, should be borax-treated similarly to that described for pine stands.

Subalpine fir

Subalpine fir is extremely susceptible to root decay, much of which that does occur is annosus root disease, especially in disturbed stands. Probably because of natural heavy stocking, cooler and moist climatic conditions associated with high elevations, stump infection and associated root disease results from smaller stumps then observed with pine and other true firs. Freshly-cut subalpine fir having a breast height of 6", or a stump diameter of at least 8" should be borax-treated to prevent *H. annosum* colonization.

Recreation sites

By nature, recreation sites have frequent and substantial disturbances, both to trees and the site. Soil compaction, root exposure and tree wounding are common and often results in root and lower butt decay. Defective trees may be removed if they are deemed to pose an unacceptable level of hazard to people and property. Stumps of removed hazard trees can introduce root disease to nearby individuals if not treated. Because of the high degree of public safety required in recreation sites, stump treatment with borax is required under Forest Service Manual direction (FSM 2331.31).

Figure 12. Annosus root disease associated with old pine stumps.

Figure 13. Toppled grand fir with extensive root decay caused by *H. annosum*

Figure 14. Grand fir with annosus root disease. Typical *H. annosus* stain and decay having irregular outer margin.

Figure 15. Laminated decay with white streaks and variable pitting on only one side of sheets typify *H. annosum*.

Figure 16. Hollow decaying grand fir stump. *H. annosum* conks are often found in stumps at least 25 years old.

Figure 17. *H. annosus* conks on the roots and root collar of sapling-size ponderosa pine.

BLACKSTAIN ROOT DISEASE

Blackstain root disease is caused by the fungus *Leptographium wageneri*, also recently known both as *Ceratocystis wageneri*, and *Verticicladiella wagenerii*. The importance of this disease was not recognized in the Blue Mountains until about 1990. Since that time, blackstain has been found to occur throughout a substantial portion of the ponderosa pine type in the southern Malheur National Forest.

L. wageneri is not a root decayer like most other root disease fungi, including those discussed in this paper, but rather it is a vascular wilt-type disease. Hyphae of *C. wageneri* grow through the tracheids of the host root, root collar, and lower bole sapwood, blocking the flow of water, resulting in moisture stress. Direct mortality may occur as a result of infection, or more frequently, attack by bark beetles contribute to demise of infected trees.

Hosts

Blackstain root disease is primarily a localized disease of ponderosa pine in the Blue Mountains. The most significant area of substantial root disease is on the southern portion of the Burns Ranger District, Malheur NF, and east of Highway 395. There have been lesser amounts of blackstain found in ponderosa pine stands elsewhere on the Burns District, as well as on other Districts on the Malheur NF. Minor scattered infections have been found on the Heppner Ranger District, Umatilla NF, and a single severely-infected plantation on Abels' Ridge, Pomeroy RD, Umatilla NF, at the northern extent of the Blue Mountains. There have been a few occasional and scattered confirmations made on other conifer species, including Douglas-fir and Engelmann spruce, but these have been characterized as minor infestations and currently do not present a management concern.

Recognition

Blackstain root disease often occurs in distinct centers, but also as less noticeable small pockets of mortality scattered throughout stands (Figure 18). In the past, this pattern of mortality in pine has been attributed solely to bark beetles, which are invariably also associated with dead and dying trees. While mortality solely due to bark beetles generally occurs for a year or two, blackstain disease and associated beetle centers will experience mortality over a number of years, usually in gradually ever-expanding pockets.

Crown symptoms are similar to other root diseases; although some trees are killed rather quickly by beetles before crown symptoms are well advanced. Reduced height growth; chlorotic and shortened needles; reduced needle retention, and minimal shoot elongation, that gives the classic "lion-tail" appearance; may be observed in infected trees within and on the perimeter of centers. Since *L. wageneri* does not cause root decay, trees remain standing after being killed. Ponderosa pine less than about 16" dbh will usually topple about 8-12 years after dying, regardless of whether killed by bark beetles or blackstain. Toppled trees will have decayed and deteriorated roots through the actions of arthropods (especially ants) and soil-inhabiting fungal saprophytes.

Symptomatic diseased trees and those recently-killed by blackstain can be examined for the presence of very characteristic brown-black to purple-black stain usually found in streaks in the sapwood of the roots and root collar (Figure 19). The outer growth ring is usually unstained, but using an ax or Pulaski to expose the inner sapwood on roots and root collar will reveal this stain and confirm infection on infected trees. When viewed in cross-section, the pattern of the stain should be concentric and associated with the annual rings. If the stain is pie-shaped in cross-section, it is likely a blue-stain fungi of *Ceratocystis sp.,* introduced by bark beetles. Blackstain-killed trees will usually have both stains.

Tree, Stand, and Community Effects

As with other root diseases, blackstain contributes to diversity in stand structure. Openings are created, often in otherwise single story stands. Scattered mortality provides snags for various cavity-nesting birds and other wildlife. These effects are really not much different than those provided by bark beetles in overstocked stands. Bark beetles, including mountain pine beetles, western pine beetles, and engraver beetles, all benefit from the reduction in vigor of infected trees. Maintenance of high endemic populations of these insects characterize stands with disease centers. Periodic mortality, and the presence of trees loaded with beetle larvae, are beneficial to species of woodpeckers that use this source of food.

The historical incidence and severity of blackstain root disease is not known. Frequent fire periodicity is known to have occurred historically throughout the pine communities currently hosting most of the known blackstain disease in the Blue Mountains. There currently is on-going research that will provide information on the effects of fire on blackstain and the insects which vector the disease (Thies *et al*. 1996, 2001). The host and vector relationships and effects of frequent cool burns, season of burn, and tree disturbances with subsequent root disease occurrence and severity are complex and the most basic relationships are not yet fully understood. Absence of fire, as well as the development of overstocked stand conditions and development of a thick duff layer, has undoubtedly influenced the incidence and severity of blackstain. The single plantation at Abel's Ridge is believed to be infected because of host stress related to severe soil compaction and the use of offsite planting stock. No infections have been confirmed in nearby natural pine stands.

Disease Spread

L. wageneri is initially introduced into susceptible stands by one or more known vectoring species of root-feeding beetles and weevils, which includes species of *Hylastes, Steremnius*, and *Pissodes*. These insects can carry spores or mycelial filaments inadvertently acquired during earlier feeding on infected trees and introduce the fungus to other susceptible hosts during subsequent feeding. Insects seem to be attracted to trees along various "edges", as the disease usually become established adjacent to roads, streams, skidtrails, harvest units, or other physical boundary or edge in susceptible host type. It is not known how far these insects carry and spread *L. wageneri*. While thinning is known to predispose Douglas-fir to blackstain in southwestern Oregon, it is not known if a similar relationship exists in Blue Mountains ponderosa pine.

Once the causal fungus is introduced into its host, the disease develops and spreads on roots and between trees across grafts and contacts like most other root diseases. The fungus can even spread a short distance directly through the soil. Rate of spread in ponderosa pine is at least twice as fast as other root diseases; about 3.2 ft. per year. Part of this higher rate of spread is likely due to the vectoring insects playing a role in spreading the disease within stands.

Unlike other common root disease fungi, *L. wageneri* is not able to function as a saprophyte. Soon after the host dies, *L. wageneri* also succumbs unless it moves onto an adjacent living host.

Management
Blackstain is a particularly difficult root disease to effectively suppress. Traditional forest management practices tend to exasperate both severity and spread of the disease. In California ponderosa pine, Cobb (1988), recommends minimizing stand and site disturbances, especially during partial harvesting. Wounds to residual trees, soil compaction, and changes in soil moisture are potential aggravating factors. Thinning of overstocked pine is also needed to maintain growth and vigor given bark beetle potential. Control and prevention strategies that will work best in the Blue Mountains are being investigated through several research studies being conducted by the PNW Research Station (Walt Thies and Chris Niwa, personal communication). In the past, a suppression tactic was used that involved a strategy of removing all hosts from infected centers including a 50- to 66-foot wide buffer, with the intended result of the fungus dying out because of the complete removal of all living host material within the infected area. To be theoretically effective, the entire infected area needed to be treated, thus substantial buffers were added beyond the periphery of symptomatic trees.

Thinning in pine communities should be avoided during the period of June though the end of September to minimize the development of *Ips* beetles that readily breed in large diameter thinning slash during these summer months. Response of blackstain insect vectors to freshly-created slash and stumps, and associated management guidelines may be different and are not clear. Likewise, thinning to reduce stocking and maintain tree vigor and resistance to bark beetles is established practice, but must also be done at the appropriate time of year to avoid favoring insect vectors. Thinning should be avoided in active root disease centers and buffers, as vector insects will preferentially infest trees already infected with *L. wageneri*, and spread the fungus to trees they subsequently visit. The role natural fire and controlled burning play with the disease, vectors and host relations still needs to be fully determined, although there is evidence that prescribed burning can increase most insect vector populations and activity. Most insect vector species show highest response to fall burns, while some respond more to spring burns (Thies *et al.* 2001). It is probable that controlling insect vector spread of blackstain under a vigorous thinning and prescribed burning program will be a challenge.

Tomentosus Root and Butt Rot

Tomentosus root disease, caused by *Inonotus tomentosus*, damages primarily Engelmann spruce in the Blue Mountains. Little information is available on the distribution and severity of *I. tomentosus* as a root disease; observations indicate that it is both common and widespread, occurring on 10 to 50% of spruce in nearly every community containing that component. Damage is often rather dramatic, both as a predisposer to tree failure, and the incidence and amount of butt and root decay. Aho (1971), in a study primarily investigating stem volume defect, found that *I. tomentosus* infected 17 percent of the spruce sampled. Of all trees with some buttrot, 43 percent were infected with *I. tomentosus*. He also found that on most trees decay extended only a short distance from the stump into the butt log. Surveys in British Columbia indicate that less than half of surveyed stands were infected, but those infected stands usually had significant damage (Lewis and Hansen 1991). Another study in British Columbia indicated that lodgepole pine also has a high rate of infection but is seldom damaged by decay (Merler *et al*. 1989). Damage to lodgepole pine in the Blue Mountains appears to also be minor.

Most spruce communities in the Blue Mountains are in riparian or high elevation upland sites with high water tables. Windthrow, oftentimes due to root decay and/or poor root anchoring, is quite common on these sites. Numerous observations of failed trees over the years and on a variety of localities by the author demonstrates that *I. tomentosus* very commonly contributes to windthrow or stem breakage in the lower butt due to extensive decay. Tomentosus-caused mortality without windthrow or breakage appears insignificant. While living trees with substantial root damage can produce crown symptoms, this seems to be an unreliable indicator of infection. Lewis (1994) investigated the correlation between incidence and severity of root disease and crown symptoms in British Columbia, was unable to accurately identify root diseased-infected trees from conditions of crowns. Poor expression of any visible indicators on spruce in the Blue Mountains makes this a very difficult disease to diagnose. The author uses a cordless drill with a 1/8 X 12" bit to sample the lower butt, root collar, and major roots of spruce in recreation sites to identify those spruce having advanced decay. Decay is identified by reduced resistance to the penetration of the bit while drilling, and sometimes the color of the sawdust. The production of the characteristic fruiting body is not frequently observed in the Blue Mountains, including sites where infection and decay are known to be severe. The lack of correlation between crown symptoms and root damage has also been observed by Merler *et al.* (1989) in British Columbia.

While *I. tomentosus* fruiting bodies are not commonly found in the Blue Mountains province, they sometimes occur. Most fungi fruit prolifically in wet microsites, that typify spruce sites, but possibly *I. tomentosus* has relatively exacting requirements for fruiting, that are infrequently met in this area. Fruiting bodies are yellow- to rusty-brown, stalked and fleshy, 1 to 2.5 inches in diameter, and emerge from the forest floor above infected roots.

Spread between trees and from stumps to regeneration has been investigated by Lewis *et al.* (1991). Spread by *I. tomentosus* is almost entirely across root contacts and requires the transfer of ectotrophic mycelium or intrabark mycelium. It does not spread by spores. Spread is invariably along small roots, 0.5 to 1.5 inches in diameter, probably because hyphae will not grow on or through bark of larger roots. Once trees are killed or cut, any *I. tomentosus* on the root system will quickly grow through the remainder and remain viable for at least 30 years (Lewis and Hansen 1991).

Decay caused by *I. tomentosus* is exposed on roots or boles of trees that have failed and on stump surfaces and "long-butts" of cull lower boles left in the woods after harvest (usually salvage). Advanced decay is characterized by elongate, spindleshaped white pockets separated by reddish brown firm wood. Decay characteristically is in the center of roots, and in severe cases where it is well advanced, it will extend up to 6 feet into the butt (Figure 20).

Lewis (1994) also found that infected trees have reduced volume increment relative to the amount of mortality of the root system. Amount of damage to the root system is related to the time since infection and the age of the tree when it became infected. Relative to other root diseases, tomentosus is slow-growing, with mortality not often occurring unless trees windthrow or break in the lower bole due to excessive decay.

Spruce beetle (*Dendroctonus rufepennis*) populations closely correspond to the amount of available down fresh host material. Often following large windthrow events, an aggressive large epidemic population develops that can be maintained for years in healthy, although susceptible (mature) spruce. Large-scale outbreaks of spruce beetle have followed catastrophic windthrow events, such as the result of a windstorm in November 1981 in the Lake Fork drainage north of Halfway, Oregon. This epidemic lasted for years, spreading through nearly all of the extensive spruce host type in the Wallowa Mountains, and resulted in the loss of most large diameter spruce. It is likely that tomentosus root disease helps maintain an active endemic population of beetles, and does pose a risk to spruce on a landscape scale if it becomes unnaturally high and predisposes large areas to windthrow/breakage at a level which would likely then develop into a beetle epidemic. Thus, conditions that tend to promote pure spruce stocking and higher-than-normal amounts of tomentosus should be recognized as being risky.

Most if not all plant communities in the Blue Mountains currently stocked with spruce are indeed historic spruce sites. It would be unrealistic to attempt to remove spruce from areas infected with root disease, especially with the wide-spread distribution of tomentosus throughout the province. Management strategies should focus on maintaining a mix of species, and to minimize actions and conditions that may exasperate tomentosus incidence and root disease severity. Especially in riparian communities, management activity has been minimal, and current direction is to avoid disturbances. This direction may result in problems over the long term, especially if near pure spruce stocking develops due to loss of seral species and progression of stand succession along with lack of natural disturbances. Other species may also be lost; for example, subalpine fir is often a predominant spruce cohort in many upland communities. Subalpine fir mortality has been excessive through most Blue Mountain sites in the last decade due to balsam woolly adelgid (*Adelges piceae*). In other cases, seral larch are lost to dwarf mistletoe (*Arceuthobium laricis*), and Douglas-fir to dwarf mistletoe (*A. douglasii*) and Douglas-fir beetle (*Dendroctonus pseudotsugae*). In some cases, cultural work can be used to increase stand diversity by emulating natural disturbance processes.

Spruce in recreation sites should be carefully checked for defect. Since there are seldom any external indicators, an increment borer or the previously described drill should be used to detect decay. Spruce with sufficient decay in the lower butt are prone to failure and should be removed if they have the potential to inflict damage in the event of failure.

SCHWEINITZII ROOT AND BUTT ROT, also known as red-brown cubical butt rot, and the fruiting body is called the "velvet-top" or "cow-pie" fungus

Schweinitzii root and butt rot, caused by *Phaeolus schweinitzii*, previously known as *Polyporus schweinitzii*, is common throughout the Blue Mountains. While in some parts of the West, *P. schweinitzii* has been found to kill small trees, this has not been observed in the Blue Mountains, where affects are butt rot and root decay mostly in older trees.

All conifers may be infected and develop decay in the butt, however, the disease and resultant decay is most common in Douglas-fir and western larch, and somewhat less frequently in ponderosa and lodgepole pines. This disease functions as a slow spreading root decayer and small pockets of infection will occur throughout susceptible stands. Mortality is almost always associated with stem breakage or failure in the lower bole, and less frequently, windthrow, due to extensive decay (Figure 21).

Recognizing infected trees is often challenging. Trees affected with schweinitzii root and butt rot do not display reliable crown symptoms. In some cases, especially with Douglas-fir, pronounced swell or flare in the butt or lower bole is apparent. Swell is associated with advanced butt rot in those trees. Characteristic conks of the fungus are sometimes be produced by the fungus on and around affected trees with advanced and extensive decay. Generally, conks are most likely to be found associated with diseased trees growing on moist sites. Ponderosa pine and dry Douglas-fir sites almost never produce fruiting bodies, although trees are infected at rates similar to those found on wet sites.

Conks are found fruiting from the duff directly over infected roots, or less frequently, emerging directly from the lower butt. Fruiting bodies are rather unique, and they are sometimes called "cow-pie" fungus, as older examples resemble these, or the velvet-top fungus. When fresh, fruiting bodies are red-yellow and have an easily bruised velvety concentric upper surface, usually stalked, and often partially buried in the duff layer. They vary in size from several inches across to over a foot in diameter (Figure 22). Within 2 to 3 months they die, turn reddish brown and punky. These old conks dry out but persist for at least several years around the bases of infected trees. Remnants of these conks are much more frequently found than fresh examples. Conks that are produced from the lower butt are usually associated with wounds. Rather then being stalked like those produced on the ground, conks associated with trunk wounds are bracket-shaped.

Spread of *P. schweinitzii,* occurs as the fungus develops from spores and grows through the duff, infecting trees through small root tips. Infection is scattered throughout stands and is believed more of a factor of stand age than tree to tree spread. Even where adjacent trees are infected, studies have shown that often different clones of the fungus were involved, which indicates infections were from different sources. In cases where there are root grafts rather than contacts, spread can readily occur between trees. Some infection occurs from airborne spores infecting trees through fresh wounds and fire scars, although the incidence of this type of spread is not believed as important as once thought.

Figure 18. Blackstain root disease in mature ponderosa pine.

Figure 19. Blue-black stain in the sapwood of ponderosa pine infected with *Leptographium wageneri*.

Figure 20. Decay in Engelmann spruce root caused by *Inonotus tomentosus*

Figure 21. Douglas-fir failure due to advanced *Phaeolus schweinitzii* decay in the butt.

Figure 22. Fresh *Phaeolus schweinitzii* fruiting body

When infection does occur, the fungus is confined to the interior of roots, growing into the lower butt and bole of trees over many years. There initially is a reddish-brown stain which develops into a dry red-brown cubical rot with shrinkage cracks as the wood deteriorates. Profound loss of structural strength characterizes long-infected trees. This disease is of substantial concern in many recreation sites. Large old trees of susceptible species having been exposed to disturbance and wounding characterize many of our recreation sites. Older trees, especially those of susceptible species, showing any butt swell, or with wounds, should be carefully examined for associated conks and checked for decay in the base using a drill as has been described. In forest communities, the typical incidence of schweinitzii root and butt rot contribute to a natural level of dead and down large diameter wood. While decay can be expected to increase in incidence and magnitude in older stands, the effects probably contribute to desirable late and old stand structure. Younger stands are seldom damaged.

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