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Management of Root Diseases by Stumping and Push-falling

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STRATEGIC IMPORTANCE

Root diseases caused by *Armillaria ostoyae*, *Phellinus weirii* and *Inonotus tomentosus* are among the most destructive forest pests in western North America. In British Columbia (B.C.) they are responsible for significant mortality and growth loss in the province's forests. While they qualify as destructive pests in a timber supply context, these native fungi can also be considered primary ecological regulators that have profound effects on stand succession and species composition. Ultimately, root disease fungi influence all major stand management objectives, whether for timber or other resources such as wildlife, water, recreation, or viewscapes. In many areas today, however, forest management practices have increased the incidence and severity of root diseases to levels above those that might be acceptable for sustainable forestry.

Current approaches to root disease management in B.C. range from conducting no treatment, to planting low susceptibility or immune species, to the machine-assisted removal of fungal inoculum from infested sites. For gently sloping, high quality sites with light soils, inoculum removal by pulling infected stumps with excavators (i.e., stumping) or by push-falling whole, infected trees is the recommended treatment. Inoculum removal can significantly reduce mortality caused by root disease fungi and, more importantly, can restore sites to near their optimal productivity.

THE PATHOGENS

Conifers attacked by any of these three root diseases will show, in approximate order of progression, reduction of shoot growth (especially the terminal shoot), chlorosis

Removal of a root-diseased stump with an excavator.

and thinning of foliage, and the stress-induced production of many undersized cones. Usually these symptoms become apparent only when more than half of a diseased root system is non-functional. Symptoms caused by light or restricted infections may never be visible above ground on stems or in crowns. Disease symptoms are also affected by stand age and species composition, and by the vigour of the fungi. Identification of these three root disease fungi is normally based on specific characteristics such as the host species affected, the type of decay they cause, and the type of fruiting body they produce (Table 1).

DISEASE CYCLE

The life cycle of these fungi consists of two phases: a parasitic phase during which the host is killed, and a saprophytic phase after death during which the host's

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dead root system is used as a food base. These fungi have no other means of persisting in the soil except in or on infested wood. None of these fungi can grow through the soil except for *A. ostoyae* which produces root-like structures – 1-3 mm diameter strands of fungal mycelia encased in melanized tissue – called rhizomorphs. All three fungi produce fruiting bodies (sporophores), but spore-initiated infection of new hosts is considered rare for *A. ostoyae* and *P. weirii* and infrequent for *I. tomentosus*.

Infested root systems of killed trees are inoculum sources that perpetuate root disease, particularly in regenerating stands of susceptible hosts. When the roots of regenerating trees contact infested roots, the fungus spreads to the new host. As roots of infected trees contact their healthy neighbours, the disease may spread further. *Armillaria ostoyae* has the unique ability to quickly colonize uninfected roots remaining on hosts it has killed, thereby ensuring its rapid transfer to the new generation of trees.

Residual inoculum has an infective life span of about 35 years, depending on stump volume and condition, meaning that trees regenerating on untreated, infested sites may be at risk for infection for a substantial period of time. In addition, since the net amount of inoculum on infested sites accumulates with each untreated cut, these diseases may have an increasing impact on succeeding generations of susceptible host trees.

Once established on the root system, each of these fungi invades woody tissues causing roots to gradually decay. Infected trees die because (1) all their primary roots have been killed, (2) their decayed structural roots result in windthrow, (3) in the case of *A. ostoyae*, mycelial fans growing in the bark and cambium have girdled stems, or (4) they have been predisposed to bark beetle attack. Susceptible hosts less than about 15 years old will die within a few years of contracting these diseases. Time to death increases with age so that *P. weirii* may need 15-20 years and *A. ostoyae* 20-30 years to kill 80- to 100-year-old Douglas-fir. Not all root-diseased trees are killed; some are able to restrict pathogen spread by different means, as evidenced by callus tissue surrounding lesions and infection sites. Trees that survive infection lose growth, and crowns of younger trees may lose their position in the canopy. In the case of a stand managed for timber, trees forced into intermediate or suppressed crown positions may die before stand rotation. Some infected trees may increase time to death by producing adventitious roots which are thought to functionally (but not structurally) replace dead roots.

Table 1 - Distribution, hosts, symptoms and signs of the three major forest root diseases of British Columbia.

Pathogen	***Armillaria ostoyae***	***Phellinus weirii***	***Inonotus tomentosus***
Disease it causes	Armillaria root disease	Laminated root rot	Tomentosus root disease
Occurrence in B.C.	predominant root pathogen of conifers in southern interior of B.C.	principal root pathogen affecting conifers in coastal B.C. and parts of the southern interior.	found most frequently in spruce-pine forests in central and northern B.C. and at higher elevations in southern half of B.C.
Susceptible species	all conifers and several hardwoods are susceptible; although western larch, ponderosa pine and white pine show decreasing susceptibility as they increase in age.	several conifers are susceptible; Douglas-fir is the most economically important host.	in B.C. has been found on: amabilis and subalpine fir, Englemann, black and white spruce, lodgepole, ponderosa and whitebark pine, western hemlock and western larch.
Immune species	none	all hardwoods	birch
Symptoms and Signs	basal resinosis (exudation of resin or pitch), particularly in resinous species such as Douglas-fir and lodgepole pine. White mycelial fans occur in the bark and cambial zone. Cream to brown coloured mushrooms have white to brown scales on their stems and caps, and there may be a conspicuous ring on the stem.	distinctive grey-white to tawny to light purple mycelia on the surface of infected roots. A brown crusty mycelial growth may be present where the fungus is exposed to the air. Setal hyphae–reddish brown whisker-like structures–often found in the mycelia are diagnostic. The fungus causes a distinctive laminated decay where the wood separates into layers along the annual rings.	stalked, tan to yellow-brown (upper surface), cream to yellow-brown (underside) sporophores on the ground around infected trees. White-pitted, honeycombed decay is bordered by pink stain in infected wood.
Not to be confused with	*Armillaria sinapina*, also common in B.C., weakly pathogenic but considered incapable of killing healthy conifers.		*Inonotus circinatus* and *Phellinus pini* which both cause a decay pattern similar to that of *I. tomentosus.*

ROOT DISEASE MANAGEMENT

Prior to creating root disease management prescriptions, forest managers should first identify which root disease they are dealing with, then estimate its incidence (proportion of trees affected) and distribution (may range from several, scattered areas of infection to a few, distinct pockets of infection). This information is most commonly obtained from ground-based surveys designed specifically for root disease. Survey designs range from regularly or randomly spaced transects to systematically spaced, variable-radius or fixed-radius plots. They rely heavily on visual assessment of crown conditions (i.e., above-ground symptoms) conducted by an experienced root disease surveyor. Foresters must be aware, however, that above-ground symptoms do not correlate well with the actual below-ground distribution of root disease fungi. Depending on the skill of the surveyor and the fungus involved, survey results will tend to underestimate disease incidence and distribution. This is particularly true for *A. ostoyae* and *I. tomentosus*. Difficulties with surveys and survey results have prompted some agencies to develop additional decision support tools to better assist them in assessing probabilities of root disease damage, or risks, in their region. For example, B.C. Ministry of Forests staff in the Nelson Forest Region have developed an Armillaria Risk Assessment Matrix that incorporates site, host, and disease factors to obtain risk scores for diseased sites. With these scores in hand, foresters writing silviculture and stand management prescriptions can estimate the risk associated with applying conventional harvesting, regeneration, and stand management methods on sites affected by Armillaria root disease.

When survey results or other tools such as a root disease risk matrix suggest that the root diseases occurring in a stand will significantly compromise management objectives for the stand, then all possible root disease management strategies, including inoculum removal, should be considered.

When prescribing treatments for root-diseased stands, resource managers must consider factors such as long-term stand objectives, stand and site conditions, treatment costs and benefits, safety, the impact of disease on the stand if nothing is done, and the compatibility of treatments with other management objectives.

Root disease management treatments are best conducted at the time of harvest and stand regeneration, when disease inoculum can be reduced through stump removal or push-falling, or when immune or tolerant tree species can be planted.

The option of not applying any treatment may be warranted on some infested sites where soils and topographic limitations or other resource values dictate. The consequences of choosing this option must be recognized, particularly on sites where timber production of susceptible species is the principal objective. These consequences include an increase in disease incidence, a concomitant reduction of the annual allowable cut because of long-term decreased productivity of infested stands, a possible failure to meet free-growing requirements, and a likely increased time for infested stands to reach minimum harvestable age. Each of these consequences will cost foresters one or more of the following:

- a reduced after-harvest profit due to a lower than expected harvest volume for the site or due to increased costs to handle dead trees and other debris,
- the necessity to restock a stand with less susceptible species that may be less commercially valuable or less productive, or
- the necessity to treat and start the stand all over again.

The two most effective means of reducing these root diseases are by:

- removing inoculum sources (infected stumps and roots) by stumping or push-falling,

or

- planting resistant species.

Management strategies that so far have proven ineffective or not practicable in reducing root disease are presented in Table 2.

A whole, root-diseased tree is push-felled with an excavator.

MANAGING ROOT DISEASES USING STUMPING OR PUSH-FALLING

Removal of infected stumps and large roots eliminates most inoculum from infested sites and minimizes carry-over of the disease into the new stand. Small-diameter roots and pieces of large-diameter roots that remain in the soil after stump removal are torn and fragmented and invaded by competing soil organisms. Although these small pieces of infested wood may have sufficient inoculum potential to kill young regeneration, they are unlikely to serve as reservoirs of inoculum.

Benefits and Costs

Inoculum removal can result in incremental growth benefits equivalent to or greater than those derived from planting, site preparation, genetic improvement, or vegetation management. Thus, inoculum removal can be viewed as an opportunity for increasing forest productivity. However, many forest managers are hesitant to conduct inoculum removal because they view it as an expensive investment with an unknown future rate of return. Managers rightly ask whether or not it is worthwhile spending $800 - $1000/ha or more to control disease. Clearly, an economic analysis of root disease management strategies would help managers decide on the best course of action. Some economic analysis of inoculum removal in coniferous stands has been conducted. Results of two studies, one conducted for *P. weirii* in western Washington State (Russell et al. 1986), the other for Armillaria root disease in New Zealand (Shaw and Calderon 1977), suggest that high disease losses encountered on non-treated sites can be reduced by inoculum removal at a cost that is justified by rates of return in the next rotation.

Forest managers might best view inoculum removal as the cost of doing business, especially since successful treatment may restore stands to near optimal productivity in one treatment. Forest managers could consider the following question: If a root diseased stand yields only 60% of that of a non-diseased stand (i.e., a stand at optimal productivity) in the present rotation and inoculum removal could increase it during the next and subsequent rotations to 80 or 90% of optimal, would you conduct an inoculum removal treatment?

Table 2. Management strategies ineffective or not practicable against forest root diseases.

Strategy	Comments and Constraints
Biological agents	• The effectiveness of these agents has not been proven in operational settings. • Adequate delivery systems for agents have not been developed. • There are no biocontrol agents registered for use against forest root diseases in Canada.
Chemical agents	• The effectiveness of some of these agents (e.g., chloropicrin, Telone II-B), has been demonstrated for laminated root rot only. • Chemicals may be considered for treating individual trees with high aesthetic value but would require application for special use permit as there are no chemical agents registered for use against forest root diseases in Canada.
Fire	• Fire will not reduce the amount of inoculum in stumps and roots. • Fire will influence the type of vegetation returning to the site, potentially encouraging a mixture of susceptible and non-susceptible species.
Fertilization	Nitrogen • May delay development of crown symptoms but also may enhance growth of some trees such that they contact inoculum sooner. Potassium • Applied on some sites in the U.S. Pacific Northwest; effectiveness against root disease has not been proven.
Wide spacing of susceptible planted trees	• Not recommended unless susceptible species are mixed with resistant or immune species or, for laminated root rot, where soils are deep and Douglas-fir is regenerated at a spacing of at least 4 m.

Potential Constraints

Despite strong evidence that inoculum removal increases stand productivity, it may have detrimental effects on tree growth in some situations. It is likely that growth effects are strongly correlated with the suitability of sites to inoculum removal and the attention paid to minimizing impact on soil factors during operations. Forest managers should always verify that sites have suitable soils for inoculum removal as this treatment is clearly not appropriate on all sites.

Inoculum removal can cause significant site disturbance, although this disturbance cannot necessarily be equated with site degradation. The removal of stumps or whole trees with heavy machinery displaces and mixes soil and forest floor components including woody debris, creates stump holes, and may also increase soil compaction. Depending on the machinery used, the operator's skill and experience, the sizes of trees and stumps, and site and soil conditions, site disturbance associated with inoculum removal operations may be considered acceptable or it may not. In general, inoculum removal is recommended for sites with a slope of less than 35% and soils with low to moderate hazard rating for mass wasting, erosion, compaction, and soil displacement.

INOCULUM REMOVAL TIPS

- Hire machine operators experienced at removing stumps and push-falling trees.
- Use an excavator that is heavy enough and powerful enough to remove stumps and push-fall trees but which minimizes site disturbance.
- When stumping, or when the root mass of a push-felled tree is bucked, ensure that operators remove the entire stump and root system and place it cut stem surface down and roots up for best exposure of inoculum to the killing effects of the sun and air. Stumps and root systems with roots hinged in the ground will be sources of infective inoculum.
- Ensure that operators search the hole left by the stump and root system for obvious, large (more than 5 cm in diameter) root pieces and place the pieces on the soil surface.

Early Techniques for Inoculum Removal

Traditionally, stumps were removed by using a bulldozer with a solid blade, which moved more soil than was desirable. Large holes were created and topsoil was mixed with subsoil. A bulldozer with a toothed (brush) blade successfully removed stumps with less movement and mixing of soil. Use of log forks on a bulldozer caused even less soil disturbance. Log forks, with 1-m-long, tusklike projections that point forward and curve up slightly, were pushed into the soil on either side of a stump, and pushed or pried the stump from the soil. As the stump was lifted and shaken, much of the soil clinging to the roots fell back into the hole. Forks produced smaller holes, moved and mixed less soil, and probably removed more infested roots than did blades. A vibrating stump puller combined lift and vibration to separate stumps and root systems from the soil with little site disturbance. This equipment successfully removed stumps up to 50 cm in diameter.

Modern Techniques

Recently, excavators with a standard bucket and a hydraulically operated gripping thumb have been recommended for inoculum removal. Excavators can extract stumps or push-fell trees while their tracks remain stationary, causing less compaction and disruption than other machines such as bulldozers. Much of the site and soil damage caused by earlier techniques resulted from tracks moving and slipping when the force necessary for a bulldozer to push stumps out was applied.

SUMMARY OF MORTALITY RESULTS FROM INOCULUM REMOVAL TRIALS

The effectiveness of stumping and push-falling in reducing root disease inoculum has been tested on a number of sites in western North America. For the majority of sites, efficacy has been determined by the incidence of mortality to susceptible trees planted on stumped or push-felled plots relative to non-treated plots. Growth data for planted trees have also been collected for some sites (Table 3). The studies summarized in Table 3 represent a wide variety of site conditions, stand types, and experimental designs. Some of the studies were established at one location only while others were replicated over several sites. Despite these differences, in all cases to date, the stumped or push-felled plots have fewer trees killed by root disease than the non-treated plots.

Table 3. Summary of mortality results from inoculum removal trials and case studies conducted in western North America. Stumping was conducted with a bulldozer at all sites except for Skimikin where a bulldozer was used to push-fell trees and then root rake the ground.

Location and Biozone*	Root Disease (fungus)	Treatment (Total no. of trees assessed across all plots)**	Percentage of trees killed by root disease across all plots**	Growth data collected? Yes or No	No. of growing seasons	Information Source
Hoodsport, Olympic Peninsula, Washington State	Laminated root rot *(Phellinus weirii)*	Not stumped (680)	18.4	Yes	20	Walt Thies USDA Forest Service PNW Research Station 3200 Jefferson Way Corvallis OR 97331 *wthies@fs.fed.us*
		Stumped (680)	4.7			
Apiary, Coast Range, Washington State	Laminated root rot *(Phellinus weirii)*	Not stumped (680)	5.4	Yes	19	Walt Thies
		Stumped (680)	1.0			
Gates, west slope Cascade Mts, Oregon	Laminated root rot *(Phellinus weirii)*	Not stumped (952)	3.5	Yes	16	Walt Thies
		Stumped (952)	0.5			
Sweethome, west slope Cascade Mts, Oregon	Laminated root rot *(Phellinus weirii)*	Not stumped (816)	5.4	Yes	16	Walt Thies
		Stumped (816)	2.5			
Stearns Creek, northwestern Washington State	Laminated root rot *(Phellinus weirii)*	Not stumped † (2000 to 1740)	Pre thin: 9.6 Post thin: 8.2	No	19	Kenelm Russell c/o Washington Dept. Natural Resources 713 E. Bowers Road Ellensburg, WA 98926 *fishtrap1@AOL.com*
		Stumped † (2000 to 1740)	Pre thin: 5.0 Post thin: 3.6			
Cowichan Valley, southern Vancouver Island, B.C. (CWHxm1)	Laminated root rot *(Phellinus weirii)*	Not stumped (529)	12.0	No	21	Rona Sturrock Canadian Forest Service Pacific Forestry Centre 506 W. Burnside Road Victoria, BC V8Z 1M5 *rsturrock@pfc.forestry.ca*
		Stumped (578)	0.9			
Copper Canyon, southern Vancouver Island, B.C. (CWHxm1)	Armillaria root disease *(Armillaria ostoyae)*	Not stumped (613)	3.6	Yes	19	Stefan Zeglen BC Ministry of Forests Vancouver Region 2100 Labieux Road Nanaimo BC V9T 6E9 *stefan.zeglen@gems1.gov.bc.ca*
		Stumped (910)	<0.5			
Skimikin, southern interior B.C. (ICHm1)	Laminated root rot & Armillaria root disease (*A. ostoyae & P. weirii)*	Not push-felled (3054)	20.5	Yes	30	Duncan Morrison Canadian Forest Service Pacific Forestry Centre 506 W. Burnside Road Victoria, BC V8Z 1M5 *dmorrison@pfc.forestry.ca*
		Push-felled (3534)	2.1			

* Biozone = biogeoclimatic zone and is only applicable to sites in British Columbia.

** Total trees across all plots included all susceptible conifers, whether planted or natural regeneration, except for Skimikin trial where all susceptible species (i.e., Douglas-fir, lodgepole pine, western redcedar, western larch, Engelmann spruce, and paper birch) were included. Plots varied in size and number for each study. At Copper Canyon, 6% of the treated area was sampled versus individual plots and at the Cowichan Valley site a single control plot at 0.36ha and a single stumped plot at 0.34ha, were assessed.

† Plots at Stearns Creek were thinned from about 2000 stems to about 1740 stems across all plots in winter 1989/90.

Additional Inoculum Removal Trials

In addition to the studies listed in Table 3, there are a number of more recent inoculum removal trials underway in B.C. (Table 4) which do not yet have sufficient data to report, including some projects investigating Tomentosus root disease.

Currently, inoculum removal using stumping or push-falling or planting resistant species are the most effective means of reducing root disease inoculum on sites in British Columbia and the Pacific Northwest of the United States. With numerous ongoing trials in place, it is likely that management strategies will be modified in the future as more information becomes available.

Root system and stem of a Douglas-fir infected by* P. weirii *and push-felled with an excavator.

Table 4. Summary of additional inoculum removal trials currently underway in British Columbia.

Location and biozone (year study initiated)	**Root Disease (fungus)**	**Inoculum Removal Method**	**Information Source**
Shawnigan Lake, southern Vancouver Island, B.C., CWHxm (1992)	Laminated root rot *(Phellinus weirii)*	Push-falling	Rona Sturrock Canadian Forest Service Pacific Forestry Centre 506 W. Burnside Road Victoria BC V8Z 1M5 *rsturrock@pfc.forestry.ca*
Nichyeskwa Creek, Bulkley Forest District, NW B.C., SBSmc (1995)	Tomentosus root disease *(Inonotus tomentosus)*	Stumping	Alex Woods B.C. Ministry of Forests Bag 5000 3726 Alfred Avenue Smithers, BC V0J 2N0 *alex.woods@gems8.gov.bc.ca*
Mount 7, Golden, B.C., ICHmk/MSdk transition (1995)	Tomentosus root disease *(Inonotus tomentosus)*	Stumping and push-falling	Eric Allen Canadian Forest Service Pacific Forestry Centre 506 W. Burnside Road Victoria BC V8Z 1M5 *eallen@pfc.forestry.ca*
Ice Road, Nakusp, B.C., ICHmw2 (1996)	Armillaria root disease *(Armillaria ostoyae)*	Stumping and push-falling	Eric Allen

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