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Silvicultural management of armillaria root disease in western Canadian forests

Duncan Morrison and Ken Mallett

Natural Resources Canada, Canadian Forest Service, Pacific Forestry Centre, 506 West Burnside Road, Victoria, British Columbia V8Z 1M5; and Northern Forestry Centre, 5320 122 Street, Edmonton, Alberta T6H 3S5.

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Armillaria ostoyae, a cause of armillaria root disease, is a normal component of many forest ecosystems in western Canada. The equilibrium between the fungus and its hosts which usually exists in undisturbed forest stands is upset in favour of the fungus by forest management practices that create stumps. Damage caused by the fungus following these management practices is described. Strategies for reducing damage are discussed.

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L'*Armillaria ostoyae*, champignon responsable du pourridié-agaric, est une composante normale de nombreux écosystèmes forestiers de l'Ouest canadien. Dans un peuplement non perturbé, cet organisme est habituellement en équilibre avec ses hôtes. Cependant, certaines activités d'aménagement forestier peuvent, en laissant des souches, rompre cet équilibre en faveur du champignon. Les auteurs décrivent les dommages causés par l'*A. ostoyae* à la suite de ces activités et traitent de stratégies permettant de réduire ces dommages.

Forests cover 45% of the area of Canada (Forestry Canada 1992) and occur in eight forest regions (Rowe 1972). These regions are defined by their tree species composition, physiography, geography, and climate. The extensive and complex nature of Canadian forests has led to forest management practices, including those for disease management, that are extensive rather than intensive in nature. Consequently, disease management practices are primarily silvicultural.

Historically, there have been few attempts to control forest diseases in Canada. This may have been due to the abundance of wood or to the cost of control relative to the benefits. Recently, it has become apparent that certain diseases, such as armillaria root disease, may be exacerbated by forest management practices and that control measures must be applied to maintain productive forests.

Armillaria root disease occurs in all forest regions of Canada. Seven species of *Armillaria* occur in western Canada (Mallett 1990, Morrison et al. 1985). One of these, *Armillaria ostoyae* (Romagn.) Herink, is widespread in British Columbia (B.C.) south of 53° N and in Alberta, Saskatchewan, and Manitoba south of 60° N. Conifers are the preferred hosts of this fungus, but broadleaved trees, shrubs, and some herbs are also attacked. In production forests in B.C., armillaria root disease causes annual losses estimated to be 2–3 million cubic metres (A. van Sickle, Pacific Forestry Centre, personal communication). Losses in prairie forests have not been estimated.

The information on damage and management strategies that follow are applicable primarily to the southern interior and the coast-interior transition in B.C. However, damage by *A. ostoyae* is being seen increasingly in both undisturbed and managed forests in the prairie provinces, and disease management to reduce losses may be appropriate on some sites.

Armillaria ostoyae is a normal component of many forest ecosystems (Mallett 1992, Morrison et al. 1991). In undisturbed stands in these ecosystems, trees with above-ground signs and symptoms of *A. ostoyae*, such as reduced terminal shoot growth and callused basal lesions, are not uncommon. Recent surveys have shown an incidence of trees with infected root systems in such stands in the B.C. interior of up to 80% (Morrison, unpublished). On most of these root systems, the fungus was viable in root lesions but its advance had been checked by the host; that is, the host and fungus were in equilibrium. The host-fungus equilibrium in undisturbed stands may be upset by abiotic (e.g. fire) or biotic (e.g. disease or insect) factors that weaken or kill trees with root lesions. The result usually is an active armillaria root disease centre with dead and dying trees.

The host-fungus equilibrium may be upset in favour of the fungus by any forest management activity that creates stumps (McDonald et al. 1987, Woods 1994, H. Merler, B.C. Ministry of Forests, personal communication, Morrison, unpublished). The stumps of trees with *A. ostoyae* root infections or with attached *A. ostoyae* rhizomorphs are partly or wholly

colonized by the fungus, usually within three years of being cut. This applies to stumps created by any of the harvesting (regeneration) systems by mechanical cutting of competing vegetation (brushing), and by precommercial and commercial thinning. Regeneration trees may become diseased after their roots are contacted by rhizomorphs produced from the roots of colonized stumps or after their roots have grown to contact colonized stump roots. In stands of precommercial thinning age and older, adjacent trees are usually in root contact; colonization of the root system of diseased trees that were cut places adjacent residual trees at risk of infection. A flush of infection and mortality usually follows colonization of stumps created by each of these management operations. Trees infected and killed by *A. ostoyae* first become evident from 5–7 years after clearcutting, brushing and precommercial thinning, to 15–20 years after commercial thinning or selection harvesting. The incidence of infected and killed trees is up to several times greater in disturbed than in undisturbed stands. In active disease centres, time-to-death following infection ranges from 1–2 years for 5-year-old trees to 10–20 years for 80–100-year-old trees.

Damage by armillaria root disease in undisturbed and managed stands

Undisturbed, mature stands. In B.C. stands of climax species, such as western hemlock (*Tsuga heterophylla* (Raf.)Sarg.) and western redcedar (*Thuja plicata* Donn:D.Don), some of which may contain 300-year-old trees, the incidence of *A. ostoyae*-infected root systems may be moderate to high; but mortality is low. In contrast, growth loss and mortality occu in mature undisturbed stands composed primarily o. seral species [Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco, western larch (*Larix occidentalis* Nutt.), lodgepole pine (*Pinus contorta* Dougl. var. *latifolia* Engelm.), and spruce (*Picea* spp.] (Fig. 1). For example, growth loss in 80-to 100-year-old Douglas-fir trees in four interior stands increased with increasing proportion of root mortality as indicated by basal resinosis (Bloomberg & Morrison 1989). Trees showing resinosis on more than 50% of basal circumference grew about 30, 40, and 50% less than healthy trees over the previous 15-year, 10-year, and 5-year periods, respectively. The percentage of dead and infected conifers in similar mature stands was 3.5 to 30 and the percentage of stand area occupied by disease centres was 8 to 32. Within disease centres, up to 95% of trees of commercial species were infected or had been killed by *A. ostoyae* (Morrison 1981).

Following clearcutting. In B.C., depending on biogeoclimatic zone, from 10% (interior Douglas-fir zone) to 80% (interior cedar-hemlock zone) of all trees in mature stands have root lesions caused by *A. ostoyae* (Morrison, unpublished). When such stands are cut, all or part of the root system of these trees is colonized. Woods (1994) found that 59–84% of stumps of several coniferous species on four sites were colonized by *A. ostoyae*. Killing of planted or naturally regenerated conifers begins around colo nized stumps 6 to 7 years after establishment (Fig. 2) In a Douglas-fir plantation, mortality at age 6–7 was 2 trees/ha/yr, increased at age 10 to 35 trees/ha/yr (2%/yr), and levelled off at age 20 to 17 trees/ha/yr (1%/yr) (Morrison & Pellow 1994).

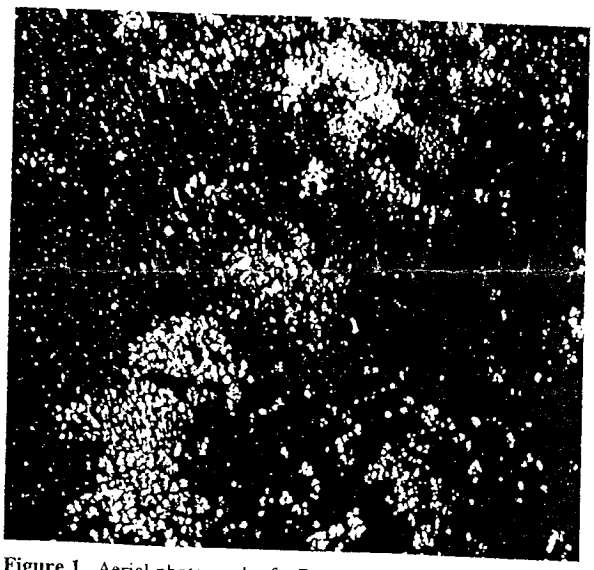

Figure 1. Aerial photograph of a Douglas-fir-lodgepole pine stand in which birch and aspen have occupied the openings created by armillaria root disease. (Photo by Ken Day)

Figure 2. Armillaria root disease centre in a 25-year-old Douglas-fir plantation. The opening is filling in with western red cedar, western hemlock, aspen, and birch.

Hopkins & Stewart (1992) surveyed for trees attacked by *A. ostoyae* in 16 randomly selected Douglas-fir plantations aged 5 to 20 years with a total area of 550 ha. On average, 18% of assessment plots contained one or more diseased trees and the incidence of dead, infected, and threatened trees was 8.6%. In many of these plantations, killing of planted Douglas-fir threatens or has reduced stocking below the required minimum. Mortality occurring in patches at an annual rate of 0.5 to 2.0% soon causes unstocked or understocked openings in the stand that become occupied by brush on dry sites and by noncommercial broadleaved species or shade-tolerant conifers on moist sites.

In Alberta, average incidence of mortality in 5- to 25-year-old lodgepole pine regeneration was about 6% per annum, and in Manitoba cumulative mortality of 25% has been observed over a 10 year period in 5- to 15-year-old red pine (*Pinus resinosa* Ait.) plantations (Mallett, unpublished).

Following precommercial thinning and brushing. Early results from an experiment in a naturally regenerated Douglas-fir stand indicate that mortality due to *A. ostoyae* in precommercially thinned plots was greater than in unthinned plots (H. Merler, B.C. Ministry of Forests, personal communication). There is abundant anecdotal evidence of increased incidence of infection and mortality among crop trees in precommercially thinned plantations and natural stands; in some stands, mortality has reduced stocking below the required minimum. These observations are in contrast to results from a ponderosa pine (*Pinus ponderosa* Laws.) stand in Oregon (Filip et al. 1989) in which there was no difference in mortality among crop trees between thinned and control plots. The different results may be related to the difference in susceptibility between ponderosa pine and Douglas-fir (Table 1) and in ecosystem characteristics; in Alberta (Ives & Rentz 1993) and B.C., damage is greater in more productive ecosystems.

Merler (H. Merler, B.C. Ministry of Forests, personal communication) found that unbrushed and chemically brushed young stands had 4 to 5% mortality among shade intolerant conifers during the preceding five years, while mechanically brushed stands had four times (up to 20%) as much mortality from *A. ostoyae* among both shade-tolerant and shade-intolerant conifers. Similarly, one of two plantations with similar inoculum levels, tree age, and species composition and topography was mechanically brushed to remove broadleaved vegetation (Woods 1994). He observed that 8.5% of conifers had been killed after treatment in contrast to 1.8% in the unbrushed plantation.

Following partial cutting. In B.C., partial cutting or selection harvesting is practiced on sites that are difficult to regenerate after clearcutting, to obtain timber of a particular species or size and to protect important visual, wildlife, or other values. Partial cutting on sites with even a low background level of root infection by *A. ostoyae* increases the incidence of infection and mortality in residual trees (Morrison, unpublished) (Fig. 3). For example, 30 years after removal of about 125 trees (40–60 cm dbh) per hectare from a site with 10% incidence of root infection, 47% of root systems were diseased, nearly all merchantable trees had been killed or were infected, and 25% of trees regenerated after harvest were dead or infected. Average merchantable volume per hectare on the partially cut portion of the stand was 170 m^3 compared to 280 m^3 on the undisturbed part (E. Begin, B.C. Ministry of Forests, personal commu-

Table 1. Host species susceptibility to *Armillaria ostoyae*

Susceptibility	Tree species[1]
High	Douglas-fir
	Abies spp.
Moderate	lodgepole pine
	jack pine
	red pine
	Picea spp.[2]
	western hemlock
	western redcedar
Low	western larch
	ponderosa pine
Resistant	birch
	aspen[3]
	poplar[3]

[1]Note that there is little difference in susceptibility among conifers less than 15 years old.
[2]In the prairie provinces, black spruce is more susceptible than white spruce.
[3]Preliminary observations suggest that aspen and poplar less than 30 years old show resistance to infection.

Figure 3. Armillaria root disease centres in a Douglas-fir stand partially cut 30 years previously. Both overstory and regeneration trees are being killed.

nication). Damage severity ratings for *A. ostoyae* were significantly higher on plots with past logging disturbance than on undisturbed plots (Woods 1994). The effect of three partial cutting entries over 25 years was seen in a mixed conifer stand near Nelson, B.C. After the third entry about 90% of the site was infested with *A. ostoyae* inoculum, resulting in serious understocking because most regeneration trees are killed before they reach merchantable size.

In Alberta, killing of white spruce [*Picea glauca* (Moench) Voss] by *A. ostoyae* has been observed in mixedwood stands following removal of the aspen (*Populus tremuloides* Michx.) overstory (Mallett, unpublished).

In summary, armillaria root disease reduces the merchantable volume at the end of the planned rotation, reduces or eliminates opportunities for stand tending such as precommercial thinning and brushing, alters the mix of species available for harvest, and may lengthen the rotation because infill trees are below merchantable size.

Figure 4. Stumping by pushover logging in an diseased stand.

Management strategies

Management strategies for root disease must be effective, should be applicable at the time of scheduled forest management activities and should incur small incremental cost. The critical points in the life cycle of *A. ostoyae* are: i) infecting, killing and colonizing a food base; ii) surviving in the foodbase until a suscept becomes available; and iii) spreading from the food base to the suscept. Currently, strategies to reduce damage by armillaria root disease are reducing inoculum, planting alternate species, and increasing escapes.

Fumigation has eradicated *Armillaria* spp. from stumps and root systems (Bliss 1951, Filip & Roth 1977); however, this treatment is too expensive and difficult to apply operationally in production forests. Application of chemicals to the root collar of infected ponderosa pines did not reduce mortality (Filip & Roth 1987).

Inoculation of stumps with other species of wood decay fungi may reduce colonization of the root system by *Armillaria* spp. (Pearce & Malajczuk 1990, Rishbeth 1976). However, the efficacy and practicability of such treatments are limited by the high incidence of root systems infected by *A. ostoyae*, by the temporal and spatial advantage that *A. ostoyae* has over potential competitors, by the numerous stumps and occurrence of up to ten host tree species on a site, by the host specificity of potential competitors, and by the frequent necessity to combine chemical treatment with inoculation of the competitor.

Inoculum reduction. On many sites, high levels of *A. ostoyae* inoculum threaten or preclude regeneration of the site with acceptable tree species, maintenance of minumum stocking levels of acceptable species and expected volume and species of timber. Current guidelines for managing sites infested by armillaria root disease (Anon 1994, Morrison et al. 1991) state that on operable sites with more than 2% of survey plots containing trees with above-ground signs of *A. ostoyae*, the amount of inoculum is to be reduced by stump removal. Stumping is usually applied during clearcut logging but it can also be done when harvesting by the selection or seed tree systems. In any case, stumps and roots are removed from the soil either by pushover logging, in which whole trees are pushed over by an excavator (Fig. 4), or by removing stumps with an excavator after conventional felling (Fig. 5). Stumping is not permitted

Figure 5. Stumping following conventional harvest.

on sites with slope greater than 30%, with fine textured soil, with subsoil that is calcareous or less than 0.6 m deep, and with high erosion or mass wasting hazard (Anon 1994).

Stumped sites can be planted with one species or a mixture of coniferous species suited to the site. Because stumping does not remove all infected roots, infection and killing of planted trees occurs when tree roots contact rhizomorphs or colonized root pieces. The limited longevity of *A. ostoyae* in these root pieces and in killed regeneration trees and the absence of root contacts among adjacent trees usually preclude development of spreading disease centres. Twenty-two years after treatment, stumping has reduced conifer mortality caused by *A. ostoyae* to 2.1% compared to 15.7% in the unstumped control (Morrison et al. 1988). A similar stumping trial is in progress in southeastern Manitoba in which red pine and jack pine (*Pinus banksiana* Lamb.) were planted following removal of jack pine stumps.

By age 12–15, when young plantations and natural stands are evaluated for precommercial thinning and brushing, most of the *A. ostoyae* inoculum has been expressed as disease centres. Chainsaw spacing and brushing increases the incidence of armillaria root disease by providing new food bases for the fungus. Therefore pop-up spacing was developed (D. Norris, B.C. Ministry of Forests) to prevent inoculum buildup by removing dead and symptomatic trees and those nonsymptomatic trees adjacent to diseased trees which were likely to be infected. Trees and root systems are pulled from the ground by a small excavator with an attachment designed for the purpose (Fig. 6). Many trees of precommercial thinning age, particularly those of less susceptible species, are able to check root infections; thus by preventing an increase in inoculum potential the likelihood of these trees surviving could be enhanced. Field trials are in progress in the southern interior of B.C.

Alternate species. There are many sites where slope, soil characteristics, and other values preclude stump removal. Planting the least susceptible species following harvest offers the best chance of maintaining timber production on these sites. Host species susceptibility to *A. ostoyae* (Table 1) was evaluated by excavating root systems of two or more species in disease centres and observing the amount of infection and host response to it. All coniferous species are moderately to highly susceptible to killing by *A. ostoyae* until they are 12–15 years old. After this age, some conifer species become less susceptible to killing (Table 1), most notably western larch and ponderosa pine, as indicated by callus formation and compartmentalization of decay at root lesions (Robinson & Morrison 1994, Shaw 1980). Broadleaved species, especially paper birch (*Betula papyrifera* Marsh.)(H. Merler, B.C. Ministry of Forests, personal communication) and perhaps aspen and poplar (*Populus trichocarpa* Torr. & Gray), show considerable resistance to infection before 30 years of age, but become moderately susceptible as they approach 50 years of age.

Use of western larch to regenerate diseased sites in B.C. is recommended wherever the ecosystem permits. Early survival of larch could perhaps be enhanced if it were planted in a mix with birch. Use of species from the susceptible and moderately susceptible categories to regenerate diseased sites is not recommended, except in mixtures with birch and perhaps larch.

During precommercial thinning, low susceptibility and resistant species can be preferred to reduce root contacts and hence disease spread between susceptible species. It is preferable to forego spacing than to

Figure 6. Pop-up spacing attachment mounted on an excavator.

risk increasing inoculum potential by cutting diseased trees, particularly if those trees have callused basal lesions.

Increasing escapes. The objective of this strategy is to reduce the probability that a suscept will contact *A. ostoyae* inoculum. This is achieved by planting trees at some distance from colonized stumps, by planting the least susceptible species next to colonized stumps, or, when the number of stumps is high, by planting alternate rows of the least susceptible and susceptible species. The Skimikin stumping trial (Morrison et al. 1988) contains plots with alternate rows of susceptible and less susceptible species. In both the stumped and control blocks, the number of disease centres and the number of trees per centre were lower in plots with alternate rows of Douglas-fir or lodgepole pine and western red cedar or birch than in plots of Douglas-fir or lodgepole pine alone. The rows of less susceptible species prevented spread of *A. ostoyae* between the rows of susceptible species.

During precommercial thinning, least susceptible species, including hardwoods, are preferred as crop trees so that spread between trees of susceptible species is reduced.

Choice of management strategy is determined by management objectives (timber and other values), site history, soil type, and topography. A different strategy may be applied to each stratum occurring on a site. The strategies described here are operational or are being evaluated in operational and research trials.

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