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Control of laminated and Armillaria root diseases by stump removal and tree species mixtures: Amount and cause of mortality and impact on yield after 40 years

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ABSTRACT

In 1968 a trial was established near Salmon Arm in the southern interior of British Columbia to determine if whole tree logging and root raking would reduce mortality in the next rotation on a site infested by *Phellinus sulphurascens*, cause of laminated root disease. In stumped and not stumped blocks, seedlings of Douglas-fir, lodgepole pine, western redcedar and paper birch were planted alone and in all combinations of two species in three 0.04 ha plots per block; western larch and Engelmann spruce were planted on one plot in each block. Tree mortality was recorded periodically by cause over 40 years. Dominant height, diameter, and basal area were measured every five years after 20 years. The highest survival after 40 years occurred in plots where stumps were removed, especially in those of Douglas-fir alone or in mixture or of spruce or larch. Mortality averaged over all species at age 40 was on average 14% lower in plots stumped (0.47) than in those not stumped (0.61). Principal causes of mortality in both blocks to year 40 were planting failure, root diseases (mainly *Armillaria ostoyae*), abiotics, thinning, and for lodgepole pine, mountain pine beetle. Stump removal and root raking improved planting survival and reduced root disease mortality caused by *P. sulphurascens* and *A. ostoyae*. For all species except pine ($p > 0.34$), spruce ($p = 0.14$), and redcedar ($p > 0.24$) and with the exception Douglas-fir with redcedar ($p = 0.005$), yield in plots stumped showed positive effects on basal area by age 40 compared to plots not stumped, especially for western larch (60, 40 m^2/ha, respectively) or Douglas-fir (56, 40 m^2/ha, respectively). By age 40, height growth was also greater (average 70 cm) in plots stumped for most species. Quadratic mean diameter (QMD) of the 10 largest trees by age 40 was not different between stump treatments despite the greater density of the plots stumped. QMD of all trees and the 10 largest trees per plots was most affected by the tree species, where plots of larch and Douglas-fir had the largest trees. Admixing of tree species usually lowered overall combined basal area and had varying effects on tree height and diameter compared to monocultures. Admixing of resistant and susceptible tree species provided little benefit on reducing disease impact in the susceptible species. Disease impact might be lowered longer-term by disease-tolerant tree species, like cedar, having low impact from both root diseases and shade tolerance, which are then positioned to take advantage of canopy gaps created by disease and insects. Admixing is affected by functional traits that alter the combining ability of the tree species and their interaction with pests.

1. Introduction

Pathogenic root inhabiting fungi (*sensu* Garrett, 1960) are a taxonomically diverse group of Basidiomycota that cause economically important root diseases of woody plants, worldwide. These fungi infect and frequently kill their hosts during the parasitic phase of their life cycle and then utilize host tissues as a food base during the saprophytic part. Both parts of the life cycle may be from a few years to a few decades in duration, depending on characteristics of host and pathogen and influence of environmental factors. Spread of the fungi from a food base to a susceptible host is usually by mycelial transfer at points of root contact because most of them are incapable of growth through soil. Fungal inoculum in a food base is long-lived and much of it is belowground. Hence, susceptible hosts may be exposed to inoculum for a long time.

Measures that have been researched for reducing losses to root diseases in plantations include fallow, palliative, crop rotation and

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mixed species planting and inoculum reduction. Greig and Low (1975) reported a reduction in mortality by *Fomes annosus* (Fr.) Bref. (*Heterobasidion annosum sensu lato*) with increasing length of the planting delay (fallow). Palliative measures were manual removal of epiphytic rhizomorphs and infected roots (Napper, 1940) and fertilization of diseased trees (Rykowski, 1981; Thies and Westlind, 2005; Wallis and Reynolds, 1974). The former was effective and the latter was not in reducing host mortality.

Crop rotation is widely used in agriculture to reduce losses from disease and species mixtures have been advocated to reduce spread and impact for many pests (Pimm, 1984). These measures are often difficult to apply in forests because of the longevity of inoculum and crop and silvics of tree species. However, lists of tree species susceptibility to infection or killing are available for some important root diseases in certain ecosystems (Cleary et al., 2008, 2011; Greig, 1979; Thies and Sturrock, 1995)

Measures to reduce the amount and longevity of inoculum of root disease fungi include ring-barking, tree or stump poisoning, fumigation, stump inoculation with saprophytic fungi, and mechanical removal. The objective of ring-barking or poisoning or both was to kill the root system of a susceptible host as quickly as possible, facilitating colonization of its roots by saprophytic fungi and halting further spread in already infected roots or those in contact with inoculum (Garrett, 1970). The method was successful in East Africa (Leach, 1939) and Malaysia (Napper, 1940; Fox, 1965). However, Swift (1970) concluded that spread of an *Armillaria* sp. from pre-existing lesions was not inhibited and was probably enhanced. In temperate regions, ring-barking and stump poisoning were ineffective in reducing colonization of root systems by *Armillaria* spp. (Redfern, 1968; Sokolov, 1964), killing of young trees or number of *Armillaria* sp. basidiomes (Punter, 1963).

Various fumigants reduced or eradicated root disease fungi in root systems (Bliss, 1951; Filip and Roth, 1977; Thies and Nelson, 1982). Use of fumigants is usually considered practicable only on a small scale or in high-value crops.

Proposed and developed by Rishbeth (1951, 1963), inoculation of stumps with *Phlebiopsis* (*Peniophora*) *gigantea* (Fr.) Jülich to reduce their colonization by *H. annosum* (*sensu lato*) is the only successful, practical biological control for a root disease. Experimental work suggested that cord forming species of *Hypholoma* may limit colonization of stumps by *Armillaria* spp. (Chapman and Xiao, 2000; Rayner, 1977; Pearce and Malajczuk, 1990).

Removal of stumps and roots from the soil to reduce the inoculum of pathogenic root inhabiting fungi was advocated first by Hartig (1874) and frequently since then (see review by Vasaitis et al., 2008). *Phellinus sulphurascens* Pilát and *Armillaria ostoyae* (Romagn.) Herink) are common in coniferous forests of the northwestern United States and southern British Columbia (Thies and Sturrock, 1995). Studies in BC, Alberta, Washington and Oregon revealed substantial impacts on survival (Morrison, 2011) and growth (Cruickshank, 2010; Cruickshank et al., 2011; Goheen and Hansen, 1993; Mallett and Volney, 1999; Thies, 1983) by laminated or Armillaria or both root diseases in managed stands. At eight stump removal trials, survival of conifers in areas where stumps were not removed ranged from 97.1% (16 years) to 81.6% (30 years, average of 92.4% after 20 years) of that in areas where stumps were removed (Sturrock, 2000). The 35-year-old trial in Washington State to control Armillaria root disease in ponderosa pine showed that stump removal promoted height but not diameter growth, and reduced the areas containing high mortality, but only for the most extensive treatment (Shaw et al., 2012). Data, especially for volume or basal area yield in most tree species challenged with root disease are not available.

The trial at Skimikin was established in 1968 by L.C. Weir to determine (1) the efficacy of inoculum removal for control of *Poria* weirii Murr. (later, *Phellinus weirii* (Murr.) Gilbn. and now *P. sulphurascens*), (2) to evaluate the resistance to killing of several tree species and (3) to observe the effect on disease spread of alternating rows of susceptible and less susceptible or immune species (Weir and Johnson, 1970). Progress reports published in 1988 (Morrison et al.) and 1998 (Morrison) showed that Armillaria root disease (*A. ostoyae)* was the biotic agent killing most trees in the trial. This paper reports the incidence and causes of mortality and their spatial and temporal distributions. In addition, the trial yielded data on the productivity of tree species in monocultures and mixtures and their interactions with disease, stump removal and time. There are potentially four effects that may alter productivity in this study, (1) growth reduction due to non-lethal infections, (2) differences in survival, (3) the stump removal treatment itself, and (4) interactions between tree species and pests; these are discussed. The proportion of surviving trees is not always a reliable indicator of belowground infection for root disease (Cruickshank et al., 2011), so that none of these effects on yields can be easily separated from the other effects in this study without destructive sampling.

2. Materials and methods

2.1. Location, design, establishment and maintenance of the trial

The trial is located at Skimikin (50°48′N, 119°26′W) near Salmon Arm, British Columbia. The site is in the mw2 subzone of the Interior Cedar Hemlock (ICH) biogeoclimatic zone (Lloyd et al., 1990) at an elevation of 750 m with a south aspect and slope of about 5%. Mean annual precipitation is 625 mm, 40% of which falls between May and September and 30% as snow. The soil is an utric brunisol occurring on a glacial fluvial deposit. The mature stand in which the trial was established consisted of 75% Douglas-fir [*Pseudotsuga menziesii* var. *glauca* (Beissn.) Franco] and 25% lodgepole pine (pine) [*Pinus contorta* Dougl. *et* Loud. var. *latifolia* Engelm. *ex* S. Wats.] with an understory composed of small numbers of western redcedar (redcedar) [*Thuja plicata* Donn *ex* D. Don] and Pacific yew [*Taxus brevifolia* Nutt.]. The overstory trees were about 80 years old. Openings in the stand caused by *P. sulphurascens* contained paper birch (birch) [*Betula papyrifera* Marsh] and trembling aspen [*Populus tremuloides* Michx.].

Two adjacent 80 m by 160 m blocks were laid out in the stand across the slope. All trees within the blocks were tallied with respect to species, diameter, condition (living or dead) and location. About 20% of the Douglas-fir and pine had been killed by *P. sulphurascens* and the cut surface of 60–70% of stumps had decay or stain typical of the fungus (Weir and Johnson, 1970. In the block designated for stump removal (stumped), trees were pushed over by a bulldozer and were yarded to the landing with roots attached; following tree removal, this block was root raked to a depth of 45 cm using a bulldozer fitted with a toothed land clearing blade. In the not stumped block, trees were felled and skidded to the landing in the conventional manner. A 10 m wide strip around the blocks was push-felled and root raked to reduce the chance of root disease entering the blocks from the surrounding stand. Each block was divided into 32, 20 m by 20 m plots.

To determine the effect of push-falling and root raking on the number, size and distribution of residual roots, pits were excavated near locations of stumps infected by *P. sulphurascens* in the push-felled surround area prior to root raking and in the not stumped area. Tree roots were collected from depths of 0–30 and 31–60 cm, taken to the laboratory and examined for colonization by fungi. The number, diameter and length of roots and the identity of fungi colonizing them (*P. sulphurascens*, *Armillaria* sp. or other) were determined for each depth class and treatment (Weir and Johnson, 1970).