Tree Mortality Caused by Root Pathogen Complex in Deschutes National Forest, Oregon

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ABSTRACT

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Tree mortality caused by root diseases was measured in a severely infected, 1,000-ha forest in central Oregon. Of trees ⩾15 cm tall, 98 (11.1%) of 885 trees per hectare (or 21.6% of the merchantable wood volume) had been killed by root diseases during the preceding 20 yr (3.9 m^3/ha per year). About 15% of the dead trees, representing over half of the dead volume, had been salvaged. *Armillaria mellea* occurred on all conifer species, *Phellinus weirii* on grand fir and Douglas-fir, *Ceratocystis wageneri* on ponderosa pine and lodgepole pine, and *Fomes annosus* on grand fir. Two or more root pathogens frequently occurred in close association. This is the first report of *C. wageneri* on lodgepole pine in Oregon and of extensive infection of ponderosa pine by *C. wageneri* in the Pacific Northwest.

Tree mortality caused by root diseases constitutes a significant loss of timber volume in Pacific Northwest forests (3). East of the Cascade Range, loss is most serious in the mixed-conifer (*Pinus-Pseudotsuga-Abies*) zone. On two sites in Washington and Oregon, *Armillaria mellea* (Vahl ex Fries) Quel. has been estimated to cause wood loss of 1.7 m^3/ha per year (15) and 3.6 m^3/ha per year (4). Loss caused by *Phellinus weirii* (Murr.) Gilbertson has been estimated at 5.6 m^3/ha per year in a southern Oregon stand (D. J. Goheen, *unpublished*). Although *Fomes annosus* (Fr.) Cke. occasionally causes tree mortality in Oregon and Washington, the pathogen more commonly causes a root and butt rot of hemlocks (8) and true firs (2). In the Pacific Northwest, *Ceratocystis wageneri* (Goheen and Cobb) infects primarily second-growth Douglas-fir west of the Cascade Range (9). However, in California, extensive damage occurs in ponderosa pine (6). Mortality caused by two or more root pathogens affecting the same tree or trees in the same infection center has been reported in several parts of the western United States (7,11).

Objectives of this evaluation were to determine tree stocking and volume losses caused by tree mortality from root disease over a severely diseased, 1,000-ha area and to investigate occurrence and relative importance of the principal root pathogens and pathogen complexes involved in tree infection and mortality.

MATERIALS AND METHODS

The investigation was done in the Sisters Ranger District, Deschutes National Forest, OR. The area contains uneven-aged stands (average age = 100 yr) composed of several conifer species. Grand fir (*Abies grandis* (Dougl.) Lindl.) and ponderosa pine (*Pinus ponderosa* Laws.) dominate, with lesser components of lodgepole pine (*P. contorta* Dougl.), western white pine (*P. monticola* Dougl.), noble fir (*A. procera* Rehd.), Pacific silver fir (*A. amabilis* (Dougl.) Forbes), and Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco). The vegetation type corresponds to the *Abies grandis* zone according to Franklin and Dyrness (5). Elevation ranges from 1,200 to 1,500 m. Annual precipitation ranges from 75 to 100 cm. Site index, the mean height of trees at age 100 yr, is 25 m. The area has a history of frequent sanitation-salvage harvests aimed at removing dead and dying ponderosa pine.

The 1,000-ha area was divided into five blocks of approximately 200 ha each. Each block was surveyed by following transects spaced at 200-m intervals across the unit. Plots were located every 40 m along transects. At each plot center, trees with diameters ⩾12.5 cm at 1.4 m from ground level (DBH) were tallied with a prism (basal area factor 20), and trees <12.5 cm DBH but ⩾15 cm in height were tallied on fixed-area circular plots (0.004 ha). Data from prism plots were used to calculate volumes and numbers of stems per hectare for trees ⩾12.5 cm DBH, and the fixed plot data were used to figure stems per hectare for trees <12.5 cm DBH but ⩾15 cm in height.

Data recorded for each tree included: a) species; b) DBH if ⩾2.5 cm (approximated for stumps); c) tree condition—live standing, windthrown, recently killed, dead 5 yr, dead 6–10 yr, dead 11–20 yr, or stump (harvested tree); and d) presence of root infection or cause of mortality if applicable. Trees or stumps with less than half of their circumference at the root collar covered by intact bark were considered to have been dead for more than 20 yr and were not examined or recorded. This method of estimating the time span that trees have been dead is based on our own experience, and although admittedly rather crude, it does provide a method of recording only relatively recent mortality.

Root diseases were detected by limited

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excavation and dissection of major roots near the root collar. Only dead trees and stumps, or trees with advanced aboveground symptoms, were examined. No attempt was made to locate root infections on symptomless trees. *A. mellea* was detected by the presence of characteristic mycelial fans beneath root collar bark or by yellow, stringy decay in old, dead material. *P. weirii* was detected by the presence of ectotrophic mycelium on exposed root surfaces or by characteristic laminated decay with setal hyphae in old, dead material. *F. annosus* was detected by the presence of characteristic white, stringy decay in old, dead material or by characteristic fruiting bodies. *C. wageneri* was detected by the presence of diagnostic brown-black stain in the sapwood of infected roots and butts (6). In addition, stained wood from five lodgepole pines and five ponderosa pines was plated on selective medium (10), incubated at 18 C for 14 days, and examined for characteristic conidiophores to confirm the species identity.

Because of the high incidence of internal decay caused by *F. annosus* as indicated from stump surfaces, a more intensive survey was done on unharvested grand fir. Fifteen recently killed and 15 live trees exhibiting advanced aboveground symptoms of decline were selected and felled throughout the survey area. Presence of root pathogens, as determined from root collar examinations, and occurrence of severe trunk wounds were recorded for sample trees. A disk 2 cm thick was removed from the base of each tree (0.5 m above ground level), placed in a plastic bag, and transported to the laboratory. In the laboratory, each disk was measured for diameter, surface sterilized in a 25% solution of sodium hypochlorite, rinsed in water, placed in a plastic bag with wet paper, and incubated for 10–14 days. *F. annosus* colonization was confirmed in infected trees by the appearance of the imperfect stage, *Oedocephalum lineatum* Bakshi, on incubated disks.

RESULTS

Sixty percent of the 1,381 plots had at least one diseased tree. Ninety-eight (11.1%) of a mean 885.3 trees per hectare, representing 21.6% of the merchantable wood volume (3.9 m^3/ha per year), had been killed by one or more of the four major root pathogens during the last 20 yr (Table 1). Another 5.7% of the trees, representing 6.7% of the volume, had been killed by other causes (other root diseases, bark beetles, wood borers, balsam woolly aphids, dwarf mistletoe, or suppression) or were too deteriorated to determine cause of death. As previously reported (12), many grand firs with root disease were also infested by the fir engraver (*Scolytus ventralis* Le Conte). Many root-diseased pines were infested by mountain pine beetle (*Dendroctonus ponderosae* Hopkins) or western pine beetle (*D. brevicomis* Le Conte).

Based on stump evidence, 15% of the dead trees, representing over half of the dead volume, had been harvested. Most of these stumps were infected by one or more root pathogens and were probably infected before tree harvest because a) *C. wageneri* infects only living trees (6) and b) *A. mellea, F. annosus,* and *P. weirii* were found in many living but highly symptomatic trees, suggesting that they had been acting as primary tree killers. According to local forest managers, only dead or dying trees had been removed. Most of the standing dead trees had been dead more than 5 yr, and 1.7% of the trees had been windthrown in the past 20 yr. All windthrown trees had root disease.

Incidence of mortality caused by root disease (Table 2) was least in trees 2.3 cm DBH (3.9%), increased in the intermediate diameter classes (13.9–16.5%), and was greatest in trees ≥27.8 cm DBH (22.9%). Incidence of mortality caused by agents other than root pathogens ranged from 4.5% in seedlings to 7.2% in trees measuring 12.5–27.7 cm in diameter.

Of the seven conifer species recorded in the area, grand fir exhibited the most mortality caused by root disease, and ponderosa pine ranked second (Table 1). Douglas-fir and lodgepole pine were less damaged by root disease than either grand fir or ponderosa pine, but mortality increased in the larger diameter classes for both species. Western white pine trees, on the other hand, were killed more commonly by root disease in the smaller diameter classes, and mortality was less common in larger diameter trees. Noble and Pacific silver fir were less damaged by root disease than either grand fir or ponderosa pine, and mortality was relatively constant through all diameter classes. Data for noble and Pacific silver fir were combined because these species are closely related, often hybridize, and are difficult to distinguish because of similarities in appearance.

A. mellea caused more mortality than *P. weirii, C. wageneri,* or *F. annosus*, but associations of more than one root pathogen were common (Table 3). Proportion of trees infected by each pathogen differed by tree species. Grand fir, noble fir, and Pacific silver fir mortality was caused primarily by *A. mellea* alone or in association with other pathogens. Almost half of the western white pine, lodgepole pine, and ponderosa pine mortality was caused by *A. mellea.* Much of the remainder of the mortality in the latter two species was caused by *C. wageneri*. Douglas-fir mortality was

Table 1. Relative frequencies of trees by condition and species

Species	Total	Healthy[a] (%)	Dead from infection by major root pathogens (%)[b] Unharvested	Harvested	Total	Dead from other causes (%)[c] Unharvested	Harvested	Total
Grand fir	375.8[d] (92.4)[e]	76.6 (65.0)	13.5 (18.1)	1.4 (9.7)	14.9 (27.8)	8.1 (4.7)	0.4 (2.5)	8.5 (7.2)
Noble and Pacific silver fir	75.6 (14.1)	88.9 (82.1)	6.2 (10.3)	0.7 (2.7)	6.9 (13.0)	4.2 (4.4)	<0.1 (0.5)	4.2 (4.9)
Douglas-fir	11.6 (6.4)	91.5 (80.0)	6.4 (2.4)	2.1 (11.0)	8.5 (13.4)	<0.1 (1.8)	<0.1 (4.8)	0.1 (6.6)
Ponderosa pine	212.5 (215.4)	83.3 (73.3)	8.0 (6.0)	4.2 (14.3)	12.2 (20.3)	3.0 (1.2)	1.5 (5.2)	4.5 (6.4)
Western white pine	8.2 (2.8)	94.0 (86.1)	3.0 (9.8)	<0.1 (0.8)	3.0 (10.6)	3.0 (3.3)	0.0 (0.0)	3.0 (3.3)
Lodgepole pine	201.6 (25.4)	91.9 (72.4)	4.8 (12.6)	0.5 (5.8)	5.3 (18.4)	2.4 (7.0)	0.4 (2.3)	2.8 (9.3)
Total	885.3 (356.5)	83.2 (71.7)	9.3 (9.7)	1.8 (11.9)	11.1 (21.6)	5.1 (2.7)	0.6 (4.0)	5.7 (6.7)

[a] No advanced aboveground symptoms.
[b] Includes living trees with advanced aboveground symptoms.
[c] *Phaeolus schweinitzii, Poria subacida, Scolytus ventralis, Adelges picea, Dendroctonus ponderosae,* and *Arceuthobium abietinum* were frequently associated with dead trees; however, the majority had no readily identifiable fungus or insect associations.
[d] Stems per hectare; all size classes.
[e] (Volume in cubic meters per hectare; only for trees ≥12.5 cm at 1.4 m from ground level.)

caused entirely by *P. weirii*.

Examination of the subsample of felled symptomatic and dead grand firs indicated that 17% of the *Armillaria*-infected trees were also infected by *F. annosus*, while about 29% of the symptomatic and dead trees without *A. mellea* were infected by *F. annosus* (Table 4). Most grand fir with *F. annosus* had one or more trunk wounds. Values in Table 3 for grand fir were adjusted to reflect the greater incidence of *F. annosus*.

A. mellea and *F. annosus* were distributed across the entire survey area. In contrast, *P. weirii* was more prevalent at higher elevations where true firs and Douglas-fir predominated, and *C. wageneri* was concentrated at lower elevations, especially where soil moisture was relatively high and either ponderosa or lodgepole pine predominated. Where tree species distribution overlapped, as was common in the 1,000-ha area, distribution of pathogen species also overlapped.

DISCUSSION

The entire 1,000-ha area is experiencing unusually severe and extensive mortality involving four major root pathogens. Mortality was associated mostly with infection by *A. mellea*, but *C. wageneri*, *P. weirii*, and *F. annosus* were also active. Significantly, *C. wageneri* was associated with dead lodgepole pine, a heretofore unreported host in Oregon. This is also the first report of extensive *C. wageneri* infection in ponderosa pine in the Pacific Northwest. Furthermore, occurrence of *C. wageneri* in very large old-growth trees as observed here is unusual. Two or more root pathogens commonly occurred in individual infection centers and even on the same trees. A higher incidence of root pathogen complexes probably existed than was reported because only a portion of each root system was examined.

Although loss of tree growth because of infection by root pathogens was not evaluated, it is probably substantial, especially in trees infected by *C. wageneri*. Many living but *C. wageneri*-infected ponderosa pines were observed throughout the area. This was especially true of large trees that exhibited what appeared to be a substantial amount of resistance. Infected trees may experience severe growth loss before they die or are harvested.

Specific reasons for the severe damage from root pathogens in this area is unknown, but the area does share several characteristics with other areas in central Oregon and Washington expressing similar damage from root pathogens (4,15): a) mean annual precipitation of 90 cm; b) mixed tree species including *Pinus-Pseudotsuga-Abies*; c) history of

Table 2. Relative frequencies of trees by condition and size class

Diameter class (cm)	Total	Healthy[a] (%)	Dead from infection by major root pathogens (%)[b] Unharvested	Harvested	Total	Dead from other causes (%)[c] Unharvested	Harvested	Total
0.0–2.3	427.4[d]	91.6	3.9	0.0	3.9	4.5	0.0	4.5
	...[e]	...	...	...	...	...	...	...
2.4–12.4	88.2	79.2	13.9	0.0	13.9	6.9	0.0	6.9
	...	...	...	...	...	...	...	...
12.5–27.7	224.1	76.3	15.0	1.5	16.5	6.5	0.7	7.2
	(31.8)	(74.8)	(14.7)	(1.4)	(16.1)	(8.7)	(0.4)	(9.1)
27.8–53.1	104.8	70.3	17.2	5.7	22.9	4.7	2.1	6.8
	(105.3)	(70.2)	(16.2)	(6.7)	(22.9)	(4.2)	(2.7)	(6.9)
53.2+	40.8	72.7	6.7	15.7	22.4	0.6	4.3	4.9
	(219.4)	(71.9)	(5.9)	(15.9)	(21.8)	(1.0)	(5.3)	(6.3)
Total	885.3	83.2	9.3	1.8	11.1	5.1	0.6	5.7
	(356.5)	(71.7)	(9.7)	(11.9)	(21.6)	(2.7)	(4.0)	(6.7)

[a] No advanced aboveground symptoms.
[b] Includes living trees with advanced aboveground symptoms.
[c] *Phaeolus schweinitzii, Poria subacida, Scolytus ventralis, Adelges picea, Dendroctonus ponderosae* and *Arceuthobium abietinum* were frequently associated with dead trees; however, the majority had no readily identifiable fungus or insect associations.
[d] Stems per hectare.
[e] (Volume in cubic meters per hectare; only trees ≥12.5 cm at 1.4 m from ground level.)

Table 3. Relative frequencies of root pathogens in dead and symptomatic trees by tree species

Tree species	Total	Root pathogen present (%) *Armillaria mellea*	*Phellinus weirii*	*Fomes annosus*	*Ceratocystis wageneri*	*Armillaria* and *Ceratocystis*	*Armillaria* and *Phellinus*	*Armillaria* and *Fomes*	Other disease causes[a] (%)
Grand	88.0[b]	26.9	27.2	10.9	0.0	0.0	3.1	6.0	25.9
fir	(32.4)[c]	(33.8)	(31.9)	(15.6)	(0.0)	(0.0)	(5.4)	(5.2)	(8.1)
Noble and Pacific	7.7	45.3	3.2	3.2	0.0	0.0	3.2	3.2	41.9
silver fir	(2.5)	(54.7)	(8.3)	(1.7)	(0.0)	(0.0)	(5.6)	(2.8)	(27.5)
Douglas-	1.0	<0.1	100.0	0.0	0.0	0.0	<0.1	0.0	<0.1
fir	(1.3)	(7.1)	(50.0)	(0.0)	(0.0)	(0.0)	(4.9)	(0.0)	(38.0)
Ponderosa	35.6	48.6	2.1	0.7	9.7	11.1	0.7	0.1	27.1
pine	(57.4)	(55.3)	(1.9)	(1.1)	(6.9)	(9.2)	(0.8)	(0.3)	(24.5)
Western white	0.5	50.0	<0.1	0.0	0.0	0.0	0.0	0.0	50.0
pine	(0.4)	(60.0)	(10.9)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(29.1)
Lodgepole	16.3	48.5	4.6	3.0	4.6	3.0	1.5	<0.1	34.8
pine	(7.0)	(35.3)	(11.8)	(0.9)	(9.4)	(5.5)	(1.8)	(1.6)	(33.7)
Total	149.1	35.3	17.9	7.8	2.8	3.0	2.3	3.7	27.2
	(101.0)	(46.5)	(13.0)	(5.7)	(4.5)	(5.6)	(2.5)	(2.0)	(20.2)

[a] *Phaeolus schweinitzii, Poria subacida, Scolytus ventralis, Adelges picea, Dendroctonus ponderosae,* and *Arceuthobium abietinum* were frequently associated with dead trees; however, the majority had no readily identifiable fungus or insect associations.
[b] Stems per hectare; all size classes.
[c] (Volume in cubic meters per hectare; only trees ≥12.5 cm at 1.4 m from ground level.)

Table 4. Relative frequencies of trees by condition and root pathogens identified from subsample of felled symptomatic and dead grand firs

Tree condition	Total	*Armillaria mellea*	*Fomes annosus*	*Armillaria* and *Fomes*	Other disease causes[a]
Live;	16[b]	10	1	1	4
symptomatic	(19.1)[c]	(15.2)	(1.5)	(0.9)	(1.5)
Recently	14	9	1	3	1
killed	(12.8)	(8.7)	(1.1)	(2.6)	(0.4)
Total	30	19	2	4	5
	(31.9)	(23.9)	(2.6)	(3.5)	(1.9)

[a] *Arceuthobium abietinum* and *Scolytus ventralis.*
[b] Number of trees.
[c] (Total volume [m^3]).

sanitation-salvage harvesting of dead and dying large-diameter ponderosa pine; and d) fire exclusion policies for 85 yr, resulting in an increase and often an overstocking of Douglas-fir and true firs in stands formerly composed predominantly of pines.

Further investigation is needed to predict whether these or other stand characteristics contribute to severe damage by root diseases. Such predictions are needed critically by foresters as guides for management direction.

Management of this particular area will be difficult. We do not believe that the current system of sanitation-salvage harvesting is beneficial. Although periodic harvest of infected trees utilizes wood that otherwise would be lost, the number of trees attaining merchantable size will continue to decrease as they contact infected stumps and die. Cutting of infected large-diameter trees may even exacerbate the root disease situation (4,15). Also, severe wounding of residual trees may occur during such harvesting. This damage may predispose trees, especially grand fir, to internal decay (1). Unless sound silvicultural prescriptions regarding root disease are applied now, we predict continuing losses from root diseases.

A management scheme favoring indigenous conifer species that are less affected than grand fir by root diseases is probably the only practical way to reduce mortality caused by root diseases in most of the area. Species manipulation must be implemented on a site-by-site basis, with the choice of species to be favored depending on what root diseases are present on the particular site. Many stands are overmature. Replacement of these stands with younger, more thrifty trees should reduce the hazard posed by root diseases. Limited operations to remove stumps of infected trees for prevention of disease spread and tree mortality may be feasible on level sites with workable soils (13,14).

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