Disease severity increased as temperatures and inoculum concentrations increased. Significant increases in severity ratings occurred among all three inoculum concentrations at 16-22°C and 28-34°C on the fifth day after inoculation. Thus, severity ratings should be made 5 days after inoculation at the above temperatures to study variations in inoculum concentration.

Inoculum concentrations of 5 x 10^7 and 2 x 10^8 CFU/ml at 22-28°C would probably provide the best results for experiments designed to evaluate disease development because significant differences in severity ratings were observed every other day through the fifth day using these treatments.

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ROOT DISEASE IN DOUGLAS-FIR PLANTATIONS IS ASSOCIATED WITH INFECTED STUMPS

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ABSTRACT

Thirty-nine of forty-three 10- to 27-year-old Douglas-fir plantations examined near Quilcene, Washington had mortality caused by either *Armillaria mellea* or *Phellinus weirii*. Mortality averaged only 0.5 trees/ha but was clustered within plantations, resulting in understocked openings of 0.04 to 0.1 ha. Mortality due to root diseases was significantly correlated with number of infected stumps.

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Additional key words: *Fomes annosus*, western hemlock, *Pseudotsuga menziesii*, aerial survey.

Mortality caused by root disease is prevalent in young Douglas-fir (*Pseudotsuga menziesii*) plantations in Oregon and Washington (3). Large infected stumps of the previous forest stand serve as inoculum for root diseases caused by *Armillaria mellea* (Vahl ex Fr.) Quél., *Phellinus weirii* (Murr.) Gilb., and *Fomes annosus* (Fr.) Cke. (7, 8, 9). Objectives of this investigation were to determine incidence and cause of tree mortality in 43 randomly selected Douglas-fir plantations on the Olympic Peninsula near Quilcene, Washington.

MATERIALS AND METHODS

Ninety-six of 140 plantations on the Quilcene Ranger District (53,440 ha), Olympic National Forest, Washington were selected for sampling. Because preliminary observations indicated mortality was infrequent in plantations less than 10 years old, 44 of the 140 plantations were not sampled. Forty-three of the 96 plantations were then randomly selected and examined. All plantations had been established on sites previously occupied by mixtures of Douglas-fir, western hemlock (Tsuga heterophylla), and western redcedar (Thuja plicata). Plantations ranged in size from 2 to 57 ha and age from 10 to 27 years old. All plantations were planted or seeded with Douglas-fir. Natural regeneration consisted primarily of western hemlock.

Recent dead and dying trees in each plantation were counted from a helicopter. The red and yellow foliage of recent dead and dying trees contrasted sharply with green healthy-appearing trees. Dead trees without needles (old mortality) were difficult to detect from the air and were estimated from ground survey.

Eleven of the 43 plantations were randomly selected for ground survey. At least one circular plot (0.04 ha) was established in the area of highest mortality in each plantation to examine as many dead and dying trees as possible and to determine the cause of death. At least one plot was established in an area with no mortality in each of the same plantations. The purpose of the ground survey was not to confirm results of the aerial survey, which for the terrain was the more accurate and efficient method, but to: 1) aid in detecting old mortality, and 2) determine causal agents of mortality.

Data collected from each plot tree included: 1) species, 2) diameter at 1.4 m above ground (dbh), 3) crown condition, and 4) if dead, cause of mortality. Root diseases were diagnosed on both live and dead trees by excavating the root collar and major roots on each tree and removing small sections of bark to expose mycelial fans or wood decay. Entire root systems of 24 trees were excavated in one plantation. Wood chips from roots of infected trees were plated on a selective medium (4) to identify pathogenic fungi.

Within each plot, species and diameter were recorded for all stumps. In most cases, major lateral roots were excavated and dissected only to reveal fungal sporophores or advanced decay. For ten hemlock stumps with advanced decay caused by F. annosus, however, major lateral roots in contact with dead or dying saplings were excavated completely and root contacts diagrammed. Samples of decayed wood were cultured on selective media to identify pathogenic decay-causing fungi.

Correlation between cause of sapling mortality and stumps/ha decayed by pathogenic fungi was tested by stepwise regression (1).

RESULTS

Thirty-nine of 43 (91%) plantations examined aerially had mortality caused by root disease. The proportion of old mortality to recent mortality was calculated to be 3 : 2 based on ground survey of nine plots with mortality. Old mortality was calculated by multiplying recent mortality figures (counted from the air) by 1.5. Total mortality was the sum of old mortality and recent mortality and averaged 0.5 trees/ha (range 0-2.3 trees/ha) for all plantations.

Table 1. Infection and mortality caused by Armillaria mellea and Phellinus weirii in two species of saplings in thirteen 0.04 ha-infected plots.

Species	Total no.	Avg dbh (cm)	% Healthy	Percent infected: Phellinus weirii Live	Dead	Total	Armillaria mellea Live	Dead	Total	Total Live	Dead	Total
Douglas-fir	143	9.9	62	7	7	14	6	18	24	13	25	38
Western hemlock	54	10.7	87	0	2	2	7	4	11	7	6	13
Total or Average	197	10.1	68	5	6	11	7	14	21	12	20	32

Eight of eleven plantations that were examined on the ground had mortality due to root disease. Two plantations had mortality that was detected aerially but was not detected on the ground. All dead trees and nearly all chlorotic trees examined in thirteen plots in eight plantations had root collar infections. Twelve percent of all green healthy-appearing trees in infected plots also had root collar infections (Table 1). More green trees were probably infected, because in most cases entire root systems were not examined. Four of twelve healthy-appearing plots in eleven plantations had living trees with root collar infections.

Examination of dead trees indicated that 72% were killed by A. mellea and the rest were killed by P. weirii. Two plots had mortality caused by both pathogens, but they were not found together on the same trees. Douglas-fir had a higher incidence of infection (38%) and mortality (25%) by root pathogens than did western hemlock (Table 1). Armillaria mellea killed 18% of all Douglas-fir and 4% of all western hemlock, whereas P. weirii killed 7% of all Douglas-fir and 2% of all western hemlock.

A total of 214 stumps, most greater than 50 cm diameter at ground level, were examined in 11 infected (two of 13 infected plots were not sampled) and 8 healthy plots. Thirty-three percent of all western hemlock stumps, the primary species, had advanced decay caused by F. annosus (Table 2). Fifteen percent of all Douglas-fir stumps had advanced decay caused by P. weirii. No advanced decay was detected in western redcedar stumps. Armillaria mellea was detected in 7% of all stumps examined.

Table 2. Percent of stumps decayed by pathogenic fungi in nineteen 0.04-ha plots.

Species	Total number	Percent with no advanced decay	Percent with advanced decay and pathogen present: Phellinus weirii	Armillaria mellea	Fomes annosus	Nonpathogenic fungi[a]
Western hemlock	144	38	7	9	33	14
Douglas-fir	48	77	15	6	8	0
Western redcedar	22	100	0	0	0	0
Total or Avg	214	53	8	7	24	9

[a]Primary nonpathogenic fungi causing decay included Ganoderma applanatum and Fomitopsis pinicola.

Table 3. Stocking density of stumps decayed by pathogenic fungi in nineteen 0.04 ha-plots.

Cause of sapling mortality	Number of plots	Stumps per hectare: Total number	No advanced decay	Advanced decay and pathogen present: Phellinus weirii	Armillaria mellea	Fomes annosus	Nonpathogenic fungi[b]
Phellinus weirii	4	291	114	69[c]	12	62	7
Armillaria mellea	5	252	104	10	25	84[c]	30
Either of above	7[a]	282	114	42	22	79[c]	25
None of above	12	257	173	7	15	20	42
Total or Avg	19	262	151	20	17	40	35

[a]Two plots had mortality caused by both P. weirii and A. mellea.
[b]Primary nonpathogenic fungi causing decay included Ganoderma applanatum and Fomitopsis pinicola.
[c]Significant (P = 0.01) correlation with cause of mortality.

Stepwise regression between incidence of tree mortality due to root disease and the number of decayed stumps resulted in the following significant (P = 0.01) positive correlations (Table 3):

1) Percent tree mortality due to *P. weirii* and number/ha of stumps decayed by *P. weirii* -- $r^2 = 0.82$
2) Percent tree mortality due to *A. mellea* and number/ha of stumps decayed by *F. annosus* -- $r^2 = 0.48$
3) Percent total tree mortality and number/ha of stumps decayed by *F. annosus* -- $r^2 = 0.67$.

Total excavation of ten hemlock stumps with aboveground advanced decay caused by *F. annosus* revealed decay caused by *A. mellea* below the ground line on lateral roots. The two distinct types of decay caused by each fungus were often present on the same root but were separated by pseudosclerotial tissue.

Dead or dying Douglas-fir saplings adjacent to the 10 excavated stumps were infected with *A. mellea* as indicated by mycelial fans and typical *A. mellea* decay. No other root pathogens were observed on or isolated from these dead or dying saplings. Excavation revealed that all infected saplings were in contact with *A. mellea*-decayed lateral roots of the stumps. Where saplings were in contact with lateral roots decayed by *F. annosus*, there was no spread of *F. annosus* to the saplings.

DISCUSSION AND CONCLUSIONS

Mortality of 0.5 trees/ha would represent an insignificant loss if it was distributed evenly throughout forest plantations; however, mortality due to root disease most often is distributed unevenly and usually occurs as clumps or patches of trees that ultimately may coalesce to form disease centers (6). In several plantations in this investigation, mortality of 20 to 30 trees was confined to one section of a plantation. Such losses resulted in understocked openings of 0.04 to 0.1 ha. Size-class frequency of stand openings was similar to those reported in 16-18 year-old Douglas-fir plantations on Vancouver Island where the majority of openings consisted of one or two dead trees (2).

Mortality of Douglas-fir saplings caused by *P. weirii* in this investigation was commonly associated with the presence of adjacent stumps with aboveground advanced decay caused by *P. weirii*. Mortality of saplings caused by *A. mellea*, however, was not associated with the presence of adjacent stumps with aboveground advanced decay caused by *A. mellea*. Instead, the majority of these stumps had aboveground advanced decay caused by *F. annosus*. Total excavation of stumps with aboveground advanced decay caused by *F. annosus* and associated with sapling mortality caused by *A. mellea*, however, revealed that all stumps decayed by *F. annosus* also had *A. mellea* decay below the ground line on distal portions of lateral roots. In British Columbia, where stumps and roots of Douglas-fir and western hemlock contained both *A. mellea* and *F. annosus*, *A. mellea* usually occupied the outer tissue (5). Additional research is needed to clarify pathological relationships between these and other root disease fungi in forest situations. Damage in several other Douglas-fir plantations in Oregon and Washington has been found to be associated with infected stumps, but reports are seldom quantified.

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COMPARISON OF PROPOSED SURVEY PROCEDURES FOR DETECTION OF FOREST CARNIVORES

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Abstract: American marten (*Martes americana*), fisher (*M. pennanti*), wolverine (*Gulo gulo*), and lynx (*Lynx lynx*) are forest carnivores believed threatened by disturbance of late-successional forests. To manage forested ecosystems for these species, effective methods for their detection must be available. Recently, the U.S. Forest Service proposed standardized survey procedures for the detection of forest carnivores; this report presents the first critical assessment of these protocols. We compared dual-sensor remote cameras and soot-coated open and covered track plates in the same study areas over an 8-month period. Of the 4 species targeted by these procedures, we detected 3 (American marten, fisher, wolverine). The remote camera method ranked highest with respect to ease of use, effectiveness, and accuracy of identifications. However, track plates performed well for 2 species and, under certain circumstances, may be the method of choice. We suggest improvements for each method and encourage that such standardized procedures be applied over wide regions.

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Key words: cameras, fisher, forest carnivores, marten, *Martes americana*, *Martes pennanti*, Montana, survey methods, track plates.

Several species of midsized forest carnivores thought threatened by disturbance of late-successional forests occur in the northwestern United States. The fisher, wolverine, lynx, and marten are all classified as "sensitive" species within 1 or more regions of the U.S. Forest Service (Ruggiero et al. 1994). Petitions have been submitted to the U.S. Fish and Wildlife Service for listing of the wolverine, lynx, and fisher under the endangered species act (L. Nordstrom, U.S. Fish and Wildlife Service, personal communication). Although petitions for listing of the fisher and wolverine have been denied as unwarranted, the lynx is currently recognized as a candidate species for listing and is expected to be proposed for listing by the U.S. Fish and Wildlife Service in June 1998.

Numerous efforts over the past 20 years have been made to identify populations of forest carnivores and determine changes in their distributions over time (Barrett 1983, Thompson et al. 1989, Kucera and Barrett 1993, Zielinski and Truex 1995, Zielinski et al. 1995, Zielinski and Stauffer 1996, and others). However, lack of broad-scale coordination in these efforts has produced fragmented data derived from a myriad of sampling methods, making it difficult to draw meaningful conclusions about species distributions throughout the region.

Recently, an attempt was made to develop standardized protocols to detect midsized forest carnivores (Zielinski and Kucera 1995). Suggested protocols cover 3 methods of detection: remote cameras, sooted track-plates, and snowtracking. Although others have compared snowtracking, track-plate boxes, and line-trigger cameras for detecting American marten (Bull et al. 1992), our study is the first to compare remote cameras and track plates via a standardized protocol applied to the suite of forest carnivores (American marten, fisher, wolverine, lynx). Because standardization of survey techniques is critical to their broad-scale application, survey methods must be compared based on these formalized protocols.

We compared remote cameras, track plates, and snowtracking for the detection of American marten, fisher, wolverine, and lynx via the protocol outlined by Zielinski and Kucera (1995). We contrasted performance of these methods based on species detection, latency to first detection (LTD), species identification, implementation effort, and cost. In making this comparison, we attempted to test the basic assumptions underlying the protocol: ". . .effort is equivalent among methods and is sufficient to determine the presence of target species in a survey area during the survey period" (Zielinski and Kucera 1995:5).

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