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R. L. JAMES, C. A. STEWART, AND R. E. WILLIAMS

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Estimating root disease losses in northern Rocky Mountain national forests

R. L. JAMES AND C. A. STEWART

Cooperative Forestry and Pest Management, United States Department of Agriculture, Forest Service, Northern Region, Missoula, MT, U.S.A. 59807

AND

R. E. WILLIAMS

Forest Pest Management, United States Department of Agriculture, Forest Service, Intermountain Region, Boise, ID, U.S.A. 83702

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Root disease losses were estimated on more than 3 million hectares of commercial forest land within seven national forests in the northern Rocky Mountains. Area estimates were made for root disease centers on all seven forests and scattered tree mortality on three forests. Tree mortality rate and associated volume loss were estimated for two forests. Approximately 31 600 ha (about 1% of the total commercial forest land) were occupied by large active disease centers discernable from large-scale aerial photographs on these forests. About 13% of the commercial forest land of three forests contained scattered root disease mortality of at least 3 trees/ha. About 35% of the annual tree mortality was associated with root diseases on two forests. Major root pathogens found were *Armillaria mellea* and *Phellinus weirii*; bark beetles often infested root-diseased trees. Recommendations for improvement of survey techniques are discussed.

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Les pertes dues aux maladies de racines furent évaluées sur plus de 3 millions hectares de forêt commerciale dans sept forêts nationales situées dans la partie nord des Montagnes Rocheuses. La superficie des ronds de mortalité a été évaluée dans les sept forêts et la mortalité isolée dans trois forêts. Le taux de mortalité et la perte de volume qui y est associée ont été estimés dans deux forêts. De vastes ronds de maladie active, visibles sur les photographies à grande échelle, convrent près de 31 600 ha soit environ 1% de la forêt commerciale. Environ 13% du territoire occupé par la forêt commerciale de trois forêts contient au moins 3 arbres morts /ha. Environ 35% de la mortalité annuelle dans deux forêts est due à des maladies de racines. Les principaux pathogènes responsables des maladies de racines sont *Armillaria mellea* et *Phellinus weirii*. Des insectes sont souvent présents dans l'écorce des arbres malades. Les auteurs font quelques recommandations pour améliorer les techniques d'inventaire.

[Traduit par le journal]

Introduction

Root pathogens are important pests in many coniferous forest stands in the northern Rocky Mountains. Importance of these diseases in affecting forest management was recognized many years ago and the need for obtaining loss information was emphasized (Stage and Alley 1972). Since 1972, estimates of root disease losses within several national forests in northern Idaho and northwestern Montana have been made (James and Stewart 1981, 1983; Stewart *et al.* 1982; Williams and Leaphart 1978). These loss estimates have helped forest managers select stands for treatment and aided forest planning. This paper summarizes our estimates of root disease losses, outlines techniques used to obtain estimates, and describes problems we encountered in our surveys.

Materials and methods

Root disease centers

Root disease centers were identified as openings in the forest canopy with dead or dying trees around the edges. Commercial forest area occupied by active root disease centers was estimated for five national forests in northern Idaho (Kaniksu, Coeur d'Alene, St. Joe, Clearwater, and Nezperce), and two in northwestern Montana (Kootenai and Lolo) (Fig. 1). All sampled forests were located west of the Continental Divide.

Large scale, vertical, aerial photography, and ground evaluations were used to survey for root disease centers (Williams and Leaphart 1978). Surveys were superimposed over existing timber inventories using primary sample units called subcompartments (Stage and Alley 1972). This method allowed access to quantitative site, stand, and pest information from timber inventories for an entire national forest. Only subcompartments within designated commercial forests (capable of producing at least 1.4 m^3 of wood · ha^{-1} · $year^{-1}$ were included in the surveys.

Subcompartment units were photographed with either color infrared or true color transparency film at an approximate scale of 1:4000. Flight lines were established to provide a 30% sidelap and the frame interval was set to obtain a 60% endlap. Ground checking was conducted within 1 year of the photographic mission.

Subcompartments were divided into stands (photo interpretation strata). Stand boundaries were characterized by discontinuities in tree height, texture, and stocking.

Subcompartments and stands were delineated and suspected root disease centers outlined on photo transparencies. Suspected centers were identified as openings in the forest canopy with dead and dying conifers on the margins and snags, windthrown trees, a few scattered live trees, and brush within openings.

All suspected root disease centers within each stand were ground checked to verify photo interpretations. Suspected diseased trees were examined for signs and symptoms of disease at their root collar and in one or more lateral roots. Most associated fungi were identified in the field on the basis of signs and decay patterns (Partridge and Miller 1974). Occasional samples were collected for laboratory isolations

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TABLE 1. Area of root disease centers within commercial forest stands on selected national forests in the northern Rocky Mountains

National forest	No. of subcompartments sampled	Total commercial area (ha)	Estimated area with root disease centers (ha)	% commercial area with root disease centers
Kaniksu	58	315 027	2 669	0.8
Coeur d'Alene	27	238 441	12 161	5.1
St. Joe	30	300 262	1 368	0.5
Clearwater	30	492 156	1 968	0.4
Nezperce	24	378 479	3 867	1.2
Kootenai	75	644 139	1 551	0.2
Lolo	62	655 614	8 011	1.0
Total	306	3 024 118	31 595	1.0

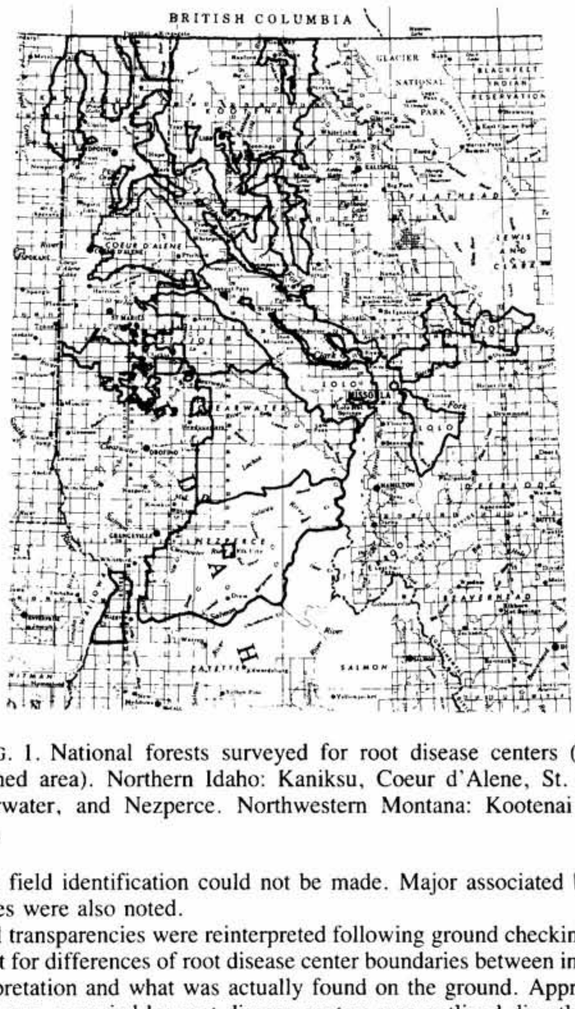

FIG. 1. National forests surveyed for root disease centers (dark outlined area). Northern Idaho: Kaniksu, Coeur d'Alene, St. Joe, Clearwater, and Nezperce. Northwestern Montana: Kootenai and Lolo.

when field identification could not be made. Major associated bark beetles were also noted.

All transparencies were reinterpreted following ground checking to adjust for differences of root disease center boundaries between initial interpretation and what was actually found on the ground. Approximate area occupied by root disease centers was outlined directly on transparencies. However, these areas could not be directly measured from transparencies because scales varied over mountainous terrain. Therefore, percentage of each stand occupied by root disease centers was first determined from photographs with a Numonics electronic graphics calculator (Numonics Corporation, North Wales, PA; approximate absolute accuracy was $\pm$ 0.6 mm). Then the percentage was multiplied by actual stand area calculated from previous timber inventories.

Root disease area within each stand was extrapolated to an entire forest on the basis of photo interpretation strata (Williams and Leaphart 1978). Weighted mean percentage of root disease for each stratum was calculated with the following formula:

TABLE 2. Area of scattered root disease mortality within commercial forest stands on selected national forests in the northern Rocky Mountains

National forest	Total commercial area (ha)	Area with scattered root disease mortality (ha)[a]	% commercial area with scattered root disease mortality
Clearwater	492 156	65 527	13.3
Nezperce	378 479	125 881	33.3
Kootenai	644 139	5 360	0.8
Totals	1 514 774	196 768	13.0

[a]Mortality of at least 3 trees/ha.

$$\mathrm{TRD}_h = \frac{\sum_i D_{hi}/P_i}{\sum_i A_{hi}/P_i}$$

whereTRD_h is the total root disease area in stratum h, D_{hi} is the area with root disease in stratum h and in subcompartment i, A_{hi} is the area in stratum h and subcompartment i, and P_i is the area of subcompartment i divided by commercial forest area of the forest. This is the probability factor by which each subcompartment was originally selected for sampling. Total commercial forest area in any photo interpretation stratum was multiplied by the appropriate TRD_h to determine commercial forest area in root disease centers.

Scattered root disease mortality

Root disease mortality unassociated with distinct infection centers was estimated on the Clearwater and Nezperce National Forests in Idaho and the Kootenai National Forest in Montana. Aerial photography used to locate root disease centers within subcompartments was also interpreted for scattered root disease mortality. Stands with at least 3 trees/ha with red or fading crowns were outlined on transparencies and were ground checked to verify the presence of root pathogens on dead and dying trees. Area within stands with consistent root disease associated mortality of at least 3 trees/ha was defined as scattered root disease mortality. Estimates of commercial forest area with scattered root disease mortality were obtained using techniques described for disease centers.

Number of trees and volume losses

To estimate annual root disease losses in terms of numbers of trees and volume, a three-stage variable probability sample was conducted on the Clearwater and Nezperce National Forests in northern Idaho. This survey was superimposed over the estimate of area occupied by root disease centers described previously. The same aerial photography was used in both surveys. Timber inventory subcompartments again served as primary sample units. Stands delineated within sub-

TABLE 3. Estimates of conifer mortality associated with root diseases on the Clearwater and Nezperce National Forests, Idaho

Mortality class	Total no. of trees (×1000)[a]	Trees/ha[b]	Volume (thousand m^3)[a]	Volume per ha (m^3)[b]
		Clearwater national forest		
Current root disease (annual)	49.2±46.9	0.1	8.0±5.3	0.02
Previous root disease	3 257.9±1 863.3	6.6	2 293.4±1 037.9	4.7
Total mortality	9 460.9±2 035.2	19.2	6 925.7±843.4	14.1
		Nezperce National Forest		
Current root disease (annual)	761.7±275.2	1.9	825.1±342.8	2.1
Previous root disease	11 505.3±5 315.2	28.9	3 650.7±3 072.8	9.2
Total mortality	34 028.0±11 174.2	85.3	17 428.8±5 510.1	43.7

[a]Values are given ± one standard error.
[b]Values are for commercial forest only.

compartments on photo transparencies served as secondary sample units. Transparent grid overlays outlined 0.4-ha cells, which served as tertiary sample units. Grid overlays subdivided the entire area within each stand. The number of cells defined by overlays varied depending on stand size.

The area within cells accounted for approximately 25% of the area within each stand; all cells were photo interpreted for tree mortality. Identified dead and dying trees were classified as being (*i*) current root disease caused mortality, (*ii*) current mortality not associated with root diseases, (*iii*) previous root disease caused mortality, and (*iv*) previous mortality not associated with root diseases. Current mortality included recently fading trees with bright yellow foliage. Snags and pale or red faders were classified as past mortality. Root-diseased trees were distinguished by their sparse foliage, chlorotic crowns, and proximity to known disease centers. Counts of dead and dying trees interpreted within cells were expanded to give estimates for stands and subcompartments for each mortality class.

Subcompartments, stands, and cells to be ground checked were selected by probability proportional to size (PPS) sampling (Cochran 1963). In PPS sampling, selection of sample units is based on frequency or size of units. In this case, the number of trees classified as past root disease-caused mortality within cells was used as the selection criterion. Nine of 24 subcompartments were selected for ground checking on the Nezperce National Forest and 7 of 30 subcompartments on the Clearwater. Number of subcompartments sampled was based on resources available for ground checking. Within each subcompartment, two stands were selected by PPS; within each selected stand, two cells were similarly chosen for ground checking.

Cells were located on the ground and all dying and standing dead trees within cell boundaries were tallied by species, measured (diameter at breast height), and examined for presence of root pathogens and bark beetles.

Tree mortality and volume data from ground surveys were expanded by multiplying weighted percentage by total commercial area to obtain forest estimates. Total number of trees per hectare in each of the four mortality classes was calculated. Estimates of the total number of trees killed by root disease were obtained by multiplying per hectare estimates by total commercial area of each forest. Volume loss estimates for each mortality class were calculated using standard USDA Forest Service Northern Region volume tables. Standard errors were calculated for each mortality class. Correlation coefficients comparing the numbers of trees from photo interpretation with those from ground surveys, and the percentage of total tree mortality associated with root diseases were also calculated.

Results and discussion

We estimated that active root disease centers occupied almost 31 600 ha or about 1.0% of the commercial forest land within the seven national forests surveyed (Table 1). Scattered root disease mortality occurred over a larger percentage of forest area in the three sampled forests (Table 2). These estimates may understate the actual extent of root diseases because they were based entirely on locating trees with aboveground symptoms. Many severely infected trees lack crown symptoms (Dubreuil 1981; James 1983). Recent studies by Wallis and Bloomberg (1981) indicate that about one-half of the root-diseased trees within and adjacent to the disease centers can be determined from aboveground symptoms. Volume losses are also incurred by such trees. Therefore, we believe our estimates are conservative and actual diseased trees are probably much greater.

Our surveys indicated that root diseases were not evenly distributed within the national forests sampled. Losses were especially high on the Coeur d'Alene National Forest because of the large number of disease centers present (Table 1) and on the Nezperce National Forest because of extensive scattered mortality (Table 2). Past forest cutting practices and differences in host and pathogen species distribution may have been responsible for the different levels of root disease present.

Current tree mortality associated with root disease was estimated at about 762 000 trees for the Nezperce and 49 000 trees for the Clearwater National Forest (Table 3). Root pathogens were found on about 35% of all dead and dying trees on both forests. We suspect that root pathogens were involved with most old-growth mortality. Root diseases accounted for more than 825 000 m^3 and 9 000 m^3 of the current volume loss within commercial forest stands on the Nezperce and Clearwater National Forests, respectively. This represented about 26% of all estimated volume loss on the Nezperce and 33% of the loss on the Clearwater National Forest. Estimating volume losses from dead trees accounts for only a portion of the true losses that may result from root diseases. Growth reduction of infected trees prior to death may also be important. To estimate true losses, more refined research work is required.

Correlation coefficients, measuring the degree of precision between photo interpretations and ground surveys, were 0.66 for total mortality and 0.58 for root disease associated mortality for the Nezperce National Forest; those for the Clearwater National Forest were 0.64 and 0.10 for total mortality and root disease associated mortality, respectively. This poor correlation between photo and ground counts and the relatively large standard errors for estimated mortality (Table 3) were probably due to errors in photo interpretation for root disease associated mortality and detection of root disease on the ground. For example, it was difficult to establish the cause of tree death from the aerial transparencies, especially on the Clearwater National Forest where extensive mortality owing to white pine blister rust was commonly found. Root disease mortality often resembled blister rust mortality. Also, many older snags resulting from root diseases were not visible on the transparencies. This was especially common in uneven-aged stands, where many snags were obscured by the canopy of larger overstory trees. Problems identifying some root pathogens on the ground and time constraints limiting root excavation also contributed to the errors.

Our system to estimate tree mortality and volume losses was derived from bark beetle surveys. However, photo interpretation and ground verification of insect attack is easy compared with root diseases. A photo survey system in which mortality from all causes is combined during photointerpretation would probably reduce errors and variability. Causes of mortality could then be determined from ground check data similar to Pest Damage Inventory sample systems (Hoskins and Norick 1982).

The most common root pathogen found on diseased trees was *Armillaria mellea* Vahl. ex Fr. It was detected on all national forests and on many different hosts including Douglas-fir, grand fir, subalpine fir, Engelmann spruce, lodgepole pine, ponderosa pine, and western larch. *Armillaria* was found within active disease centers as well as on scattered root-diseased trees. The second most common pathogen was *Phellinus weirii* (Murr.) Murr. This fungus was found on Douglas-fir and grand fir, primarily within the Kaniksu, Coeur d'Alene, St. Joe, and Kootenai National Forests. Trees infected with *P. weirii* were mostly confined to obvious mortality centers. Other pathogens found during the surveys included *Phaeolus schweinitzii* (Fr.) Pat., *Fomes annosus* (Fr.) Cke. (=*Heterobasidion annosum* (Fr.) Bref.), and several black-staining organisms in the genus *Verticicladiella*. These other fungi were mostly detected within scattered root-diseased trees. They were encountered much less frequently than were *A. mellea* and *P. weirii*. However, observations suggest that *P. schweinitzii* is very common, but is difficult to detect and does not kill trees rapidly.

Bark beetles were often associated with root-diseased trees. Major beetle species included the following: mountain pine beetle (*Dendroctonus ponderosae* Hopkins) on lodgepole pine, Douglas-fir beetle (*Dendroctonus pseudotsugae* Hopkins) on Douglas-fir, western balsam bark beetle (*Dryocoetes confusus* Swaine) on subalpine fir, and fir engraver (*Scolytus ventralis* LeConte) on grand fir. Most mature root-diseased Douglas-fir, grand fir, and subalpine fir were infested with bark beetles. However, associations between root-diseased lodgepole pine and mountain pine beetle were less definite.

Our technique for obtaining estimates of the extent of root disease centers and scattered tree mortality over large forested areas were relatively simple and inexpensive; we believe they provided fairly accurate estimates of current losses. Although we used timber inventory subcompartments as sample units, any forest subunit such as stands or photo interpretation classes can be used in a survey scheme similar to ours. Any system of estimating root disease losses will have to deal with problems of disease detection on the ground. Without extensive root excavations, estimates of infection based on aboveground or basal symptoms will be conservative. However, it is important to obtain accurate loss estimates so that forest management activities can be adjusted to reduce future losses.

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