Impact of Dothistroma Needle Blight and Armillaria Root Rot on Diameter Growth of Pinus radiata

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ABSTRACT

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The impact of Dothistroma needle blight (caused by *Dothistroma pini*) and Armillaria root rot (caused by *Armillariella novae-zelandiae* or *A. limonea*) on diameter increment at breast height of 8- to 10-yr-old *Pinus radiata* trees was measured with vernier-scale dendrometer bands. The sample trees were selected for similarity of means and variances in stem diameter and height before measurements began. Although infection by the fungi, either alone or in combination, did not alter the pattern of weekly or seasonal diameter increment, infection by *D. pini* alone was associated with a 17-73% annual loss in growth compared with noninfected trees and that by *Armillariella* alone with a 14-24% annual loss. Growth reduction in trees heavily infected by both fungi was greater than the sum of the losses attributable to heavy infection by each fungus alone. With Dothistroma needle blight, diameter growth was inversely related to the percentage of foliage affected and small trees grew significantly less than large trees with similar infection intensities. With Armillaria root rot there was no significant difference in growth between the two infection categories used (65-80% or >90% of the root collar expressing symptoms and/or signs of infection), but during the study year one-third of the severely affected trees died or were blown down by wind. Dendrometer bands were useful in quantifying losses in tree growth that are attributable to disease and that may affect forest management and productivity.

Additional key words: forest mensuration, disease-loss appraisal.

Increment loss, especially in young stands, can be the most serious influence of disease on forest production (2). Yet loss of potential growth is frequently difficult to recognize and to quantify. The single most common tree measurement recorded by foresters is trunk diameter at breast height (d.b.h.). Several years of such measurements on many trees usually are required to detect differences in growth associated with disease or silvicultural treatments, and over such long periods other factors may affect growth and obscure the influence of a pathogen. The intensity of disease also may change, making it difficult to quantify the effect of a given level of infection.

To avoid such difficulties, dendrometer bands (which measure changes in stem diameter) have been used to obtain accurate short-term growth data. Breitsprecher and Hughes (1) cited studies indicating the suitability of these devices for use in diverse environments, but the use of such instruments for detecting the influence of pathogens on forest tree growth has been rare (9).

In this study we used vernier-scale dendrometer bands to record growth patterns of *Pinus radiata* D. Don trees, healthy and variously affected by two different diseases, Dothistroma needle blight and Armillaria root rot (caused respectively by *Dothistroma pini* Hulbary and by either *Armillariella novae-zelandiae* Stevenson or *A. limonea* Stevenson).

MATERIALS AND METHODS

Description of sites.—Three *P. radiata* plantations in the central North Island of New Zealand were used. All were on deep, water-retentive pumice soils (18) of adequate fertility (8), where rainfall was high (>1,400 mm/yr) and evenly distributed.

Site 1 was on the Kaingaroa plateau, 60 km southeast of Rotorua. This 10-yr-old second-rotation stand was stocked with 250 stems/ha. Gilmour (5, and *unpublished*) has used the area for spraying trials to control Dothistroma needle blight; trees with various degrees of infection were present. As with most second-rotation pine plantations (11), the incidence of Armillaria root rot was low.

Site 2, on the Mamaku plateau 16 km west of Rotorua, was planted in 1966 after the clearing of a native (podocarp/mixed hardwood) forest. Stocking in 1975 was 300 stems/ha, of which 62% were infected to various degrees with *Armillariella* at ground level (15). Through pruning of lower infected branches and spraying with copper fungicide (4), *D. pini* infection was near zero in October 1975 when study trees were selected.

Site 3, 7 km south of Site 2, was planted in 1968 after the clearing of native forest, and was unthinned and unpruned prior to tree selection in October 1975. Trees of all crown classes and with differing degrees of infection of both *D. pini* and *A. novae-zelandiae* were present.

Selection of study trees.—At Site 1, *D. pini* infection levels were rated visually at the beginning of and twice

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during the period of observation. Ratings were estimates of the percentage of the live crown which had been defoliated by or was heavily infected with *D. pini* (5; D. A. Bartram, *unpublished*). Trees within two levels of infection (20-45% and 60-90%) and controls (< 5% infection) were selected for equivalent distribution of initial tree diameters and heights. These variables may affect the rate of diameter growth in healthy *P. radiata* (10) so their equivalence at the beginning of observation was necessary. As defoliation by *D. pini* affects crown character (3) equivalent depths of green crown could not be assured.

Fig. 1. Vernier scale dendrometer band in place on a stem of *Pinus radiata*. The spring which holds the aluminum band in place is attached again to the band, out of the picture, left. Tree growth expands the spring which changes the relative position of the scales and allows growth increments to be calculated. This scale reads (79.5 mm) 3.13 inches.

On Site 2, trees known to be infected (15) were reexamined and the percentage of the trunk circumference at ground-level expressing evidence of *Armillariella* infection (resinosis associated with rhizomorphs and/or mycelium) was measured. Controls with no visible symptoms or signs of attack and trees within two levels of infection (65-80% and >90% girdling) were chosen. Trees in these three category samples were dispersed throughout the stand and had equivalent heights, d.b.h., and depths of green crown.

On Site 3, trees were selected for varying levels of *Armillariella* infection (50-100% girdling). Trees not infected with *Armillariella* in the root collar region, but of comparable height, d.b.h. and crown class, were also chosen. All were rated visually for level of *D. pini* infection at the beginning of and twice during the study. For analysis, trees were grouped by initial size class and infection levels for one or both diseases.

Descriptive statistics for initial population parameters are given in Table 1 and Figs. 2 and 3. As the levels of *D. pini* and *Armillariella* infection did not change appreciably during the study, initial infection ratings were used.

Band description and data collection.—The vernier-scale dendrometer bands (6) were made from aluminum strips, 1.3 cm wide and 0.03 cm thick (Fig. 1). Bands were placed on the trees near breast height and held in place by a steel spring exerting a starting tension of 0.7 kg and reaching a maximum of 1.8 kg when extended to the limit of the scale (12.5 cm). This tension held the band in

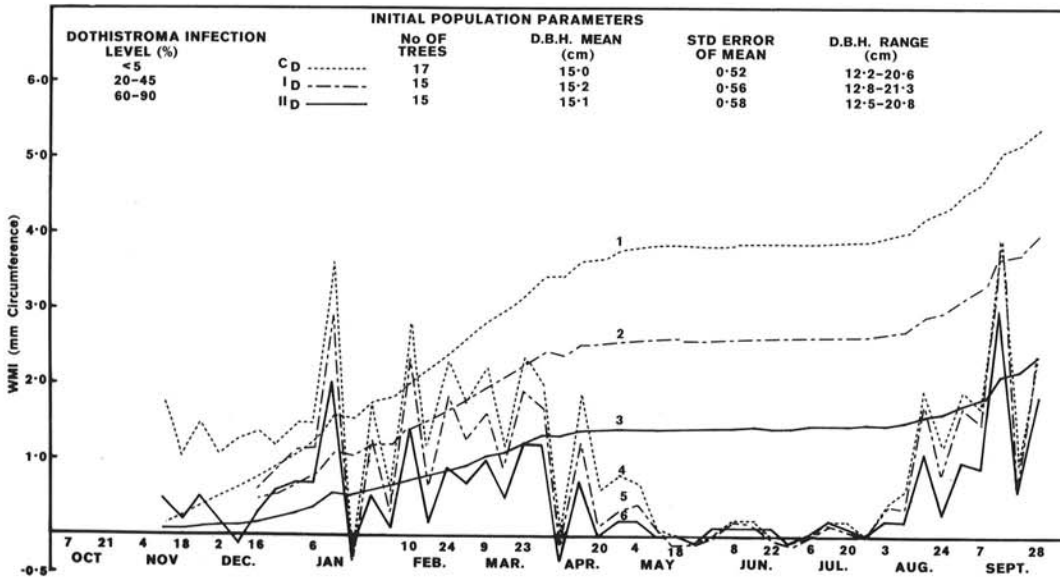

Fig. 2. Cumulative mean increment (CMI), right ordinate (lines 1, 2, and 3), and weekly mean increment (WMI), left ordinate (lines 4, 5, and 6), for trees noninfected (C_D), moderately infected (I_D), and heavily infected (II_D) with *Dothistroma pini*. The CMI for C_D and I_D, I_D and II_D, and C_D and II_D differed significantly ($P < 0.01$) after 16 December, 6 January, and 11 November, respectively.

place, yet allowed the force of tree growth to extend the spring and not "envelop" the band. Rough flaky bark was lightly rasped away so that the band would fit firmly.

Circumference scales, graduated in 0.254-mm (0.01-inch) units, were made of plastic coated aluminum foil with an adhesive back to attach them to the band. Stem circumference increments (to nearest 0.01 in., converted to 0.1-mm units) were recorded weekly from October-November 1975 through September 1976.

Data were analyzed by unpaired Student's *t*-tests and multiple regression.

RESULTS

Impact of Dothistroma needle blight (Site 1).—There were highly significant ($P < 0.01$) growth differences between uninfected (C_D) trees and those in both infection categories, and between the two infection categories (Fig. 2). After 47 wk the cumulative mean increment (CMI) for noninfected trees was 26% and 56% greater than the CMI for trees in the lower (I_D) and higher (II_D) infection categories, respectively. Relative differences in weekly increments between infection categories were notably constant despite wide short-term and seasonal variations in growth rate.

When trees were grouped according to initial diameters into "large" (16.4 cm mean d.b.h.) and "small" (13.2 cm mean d.b.h.), large trees grew significantly more ($P < 0.05$) than small trees within each infection category. These growth differences were related to infection level: after 47 wk the differences in CMI between large and small trees were 17%, 42%, and 57% for C_D, I_D, and II_D, respectively. Comparisons between infection categories, but within size classes, also suggested that small trees suffer more severely. For large trees, after 47 wk the differences in CMI between C_D and I_D, I_D and II_D, C_D and II_D were 17%, 38%, and 48%, respectively. The corresponding differences for small trees were 50%, 54%, and 73%, respectively.

Impact of Armillaria root rot (Site 2).—There was a highly significant ($P < 0.01$) growth difference between control trees (C_A) and those in the less severe infection category (I_A) (Fig. 3). After 52 wk the CMI for C_A was 14% greater than for I_A. As with trees infected by *D. pini*, trees infected with *Armillariella* followed the same weekly and seasonal pattern of growth as control trees.

All C_A and I_A trees survived; however, 10 of the original 29 severely infected (II_A) trees were lost. Seven of these died and three were blown down by wind, breaking at the root collar. All seven of the killed trees were fully girdled, as were eight of the surviving ones. Sub-sampling C_A and I_A to leave trees of initial sizes comparable to those surviving in II_A, showed no significant difference ($P > 0.05$) in growth between I_A and II_A. Both I_A and II_A sub-samples had significantly less growth ($P < 0.01$) than C_A (20% and 19% after 52 wk, respectively).

When trees were grouped into "large" (19.2 cm mean d.b.h.) and "small" (15.6 cm mean d.b.h.), large C_A, I_A,

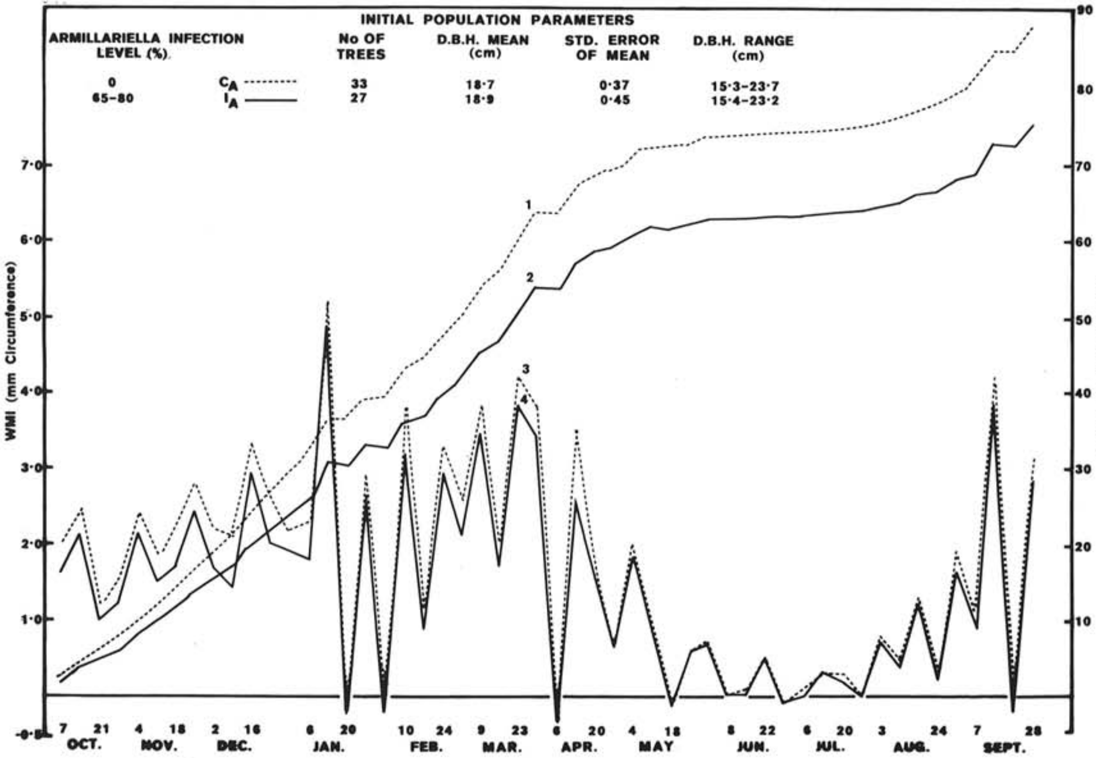

Fig. 3. Cumulative mean increment (CMI), right ordinate (lines 1 and 2), and weekly mean increment (WMI), left ordinate (lines 3 and 4), for trees noninfected (C_A) and moderately infected (I_A) with *Armillariella*. The CMI differed significantly ($P < 0.05$) after 7 October and ($P < 0.01$) after 25 November. Increments for severely infected trees (II_A) are not given because they did not differ significantly ($P > 0.05$) from I_A.

and $\mathrm{II_A}$ trees grew only slightly more ($P>0.05$) than small $\mathrm{C_A}$, $\mathrm{I_A}$, and $\mathrm{II_A}$ trees, respectively. Although small $\mathrm{I_A}$ trees showed the greatest reduction in growth (24% less CMI than small $\mathrm{C_A}$ trees after 47 wk), comparisons between infection categories, but within size classes, showed no significant differences ($P>0.05$).

Combined impact of Dothistroma needle blight and Armillaria root rot (Site 3).—Grouping trees solely on the presence or absence of infection by *Armillariella* showed no significant difference ($P>0.05$) in growth; the CMI for infected trees (24 trees, 12.8 cm mean d.b.h.) was only 7% less than the CMI for control trees (20 trees; 12.8 cm mean d.b.h.) after 47 wk. When trees were grouped solely on the level of *D. pini* infection, those with a low level of infection (<25% defoliation, 8 trees, 13.0 cm mean d.b.h.) showed significantly more ($P<0.01$) growth, 36% after 47 wk, than those with a high level of infection (>50% defoliation, 11 trees, 13.0 cm mean d.b.h.).

When trees were grouped by infection levels of both diseases, the CMI for those infected to more than 50% with both diseases ($\mathrm{I_DI_A}$) was significantly less ($P<0.01$) than for trees infected more than 50% with *D. pini* alone ($\mathrm{I_DC_A}$; Table 1). The CMI for $\mathrm{I_DC_A}$ was significantly less ($P<0.05$) than for trees infected with neither disease (no *Armillariella* and <25% *D. pini*, $\mathrm{C_DC_A}$). After 47 wk the CMI for $\mathrm{I_DI_A}$ was 53% less than for $\mathrm{C_DC_A}$. As with trees infected by one pathogen alone, those infected with both fungi followed the same weekly and seasonal pattern of growth as nondiseased trees.

After 32 wk a multiple regression of CMI on percentage of *D. pini* infection (D), percentage of infection by *Armillariella* (A), A × D, height, d.b.h., and crown class, yielded an R^2 of 0.774 with diameter, crown class, and D being significant ($P<0.05$) independent variables. Elimination of the nonsignificant variables left an R^2 of 0.758.

DISCUSSION

The data show that various levels of two markedly-different diseases significantly reduced the growth of infected trees within production-oriented forest stands. Yet, how this disease-caused growth reduction actually affects the tree crop is determined by other factors.

If a stand is uniformly infected with *D. pini* to a level of $\mathrm{I_D}$ or $\mathrm{II_D}$, our data can be related reasonably well to a growth loss for the entire stand. However, trees of various infection-intensities are frequently distributed throughout the stand. If scattered trees within the stand remain perennially but only light-to-moderately infected, then the disease may do little more than dictate the selection of crop trees for thinning. The prevalence of such a disease pattern has complicated attempts to set criteria for copper spraying to reduce disease levels and prevent losses (J. Gilmour, *personal communication*). Whyte (17) suggested that the disease has little impact until defoliation is greater than 25% of the current year's foliage (approximately 30-35% by our rating system) on 50% or more of the trees in the stand.

With Armillaria root rot, severely affected stands characteristically have an irregular stocking owing to patchy mortality (11). Visual recognition of living infected trees is not as straightforward as for Dothistroma needle blight. Trees of apparent "low vigor" are removed in thinning operations. Site 2 was thinned shortly before tree selection and all study trees had been chosen as final crop trees. With the growth loss occurring on the designated final crop, it is manifested in full as a disease-caused reduction in stand production.

Neither disease altered the pattern of growth in comparison to that of healthy trees, but it cannot be assumed that the means by which growth was reduced is the same. Defoliation by *D. pini* directly reduces foliage available for photosynthesis. However, photosynthate produced per unit of noninfected foliage may be rather greater in diseased trees than in healthy ones (16).

In contrast, infection by *Armillariella*, and probably the tree's resin response thereto (14), kills a portion of the stem base and likely impairs transportation of water and nutrients (13). This would conceivably reduce the overall effectiveness of the crown, but might not lessen the number of needles present. Rykowski (13) suggested that an above-ground symptom of Armillaria root rot was a diminution in needle length and that this symptom was observed when transportation was altered. Trees in category $\mathrm{II_A}$ had significantly smaller-sized needles than needles from noninfected trees (C. G. Shaw III and M. MacKenzie, *unpublished*).

Although the diameter growth pattern was not altered by either disease, the trees were not subjected to prolonged environmental stress because of the high and even distribution of rainfall and the favorable soil conditions. In western Washington State (USA), a region with low summer rainfall, the pattern of diameter growth for young *Pseudotsuga menziesii* (Mirb.) Franco infected with *Armillariella* was different from that of healthy trees (J. N. Woodman, *unpublished*). The seasonal pattern and week-to-week fluctuations of growth likely resulted, at least in part, from environmental influences (7). Similar patterns were noted throughout the same year in different New Zealand forests in *P. menziesii*, *P. radiata*, and

TABLE 1. Cumulative mean increments (CMI)[y] for Site 3 trees after 47 wk considering the infection levels of both *D. pini* ($\mathrm{C_D}$ = lightly infected, < 25%; $\mathrm{I_D}$ = heavily infected, > 50%) and *Armillariella* ($\mathrm{C_A}$ = absent; $\mathrm{I_A}$ = girdling > 50%)

Infection category	No. of trees	Mean d.b.h. (cm)	Std. error of mean	d.b.h. range (cm)	CMI (mm)
$\mathrm{C_DC_A}$	4	13.0	0.51	11.5 - 13.0	62.9 a
$\mathrm{C_DI_A}$	4	13.2	0.65	11.7 - 14.5	63.5 a
$\mathrm{I_DC_A}$	7	13.1[z]	0.79	10.5 - 16.5	47.6 b
$\mathrm{I_DI_A}$	5	12.3	0.28	11.8 - 13.2	29.5 c

[y] The CMI values followed by different letters differ significantly, $P<0.05$.

[z] A different sub-sample of $\mathrm{I_DC_A}$ with a mean d.b.h. of 12.2/cm (seven trees) had a CMI of 46.7, showing that the difference between $\mathrm{I_DI_A}$ and the other three categories is not due to its slightly smaller mean d.b.h.

Eucalyptus regnans F. Muell. (J. N. Woodman, *unpublished*).

Our data on the impact of *D. pini* complement Gibson's review (3) on the impact and control of this disease. Gibson cited data for trees less than 4 yr old, whereas our data are for well-established 10-yr-old trees and the growth loss is related to specified levels of infection for a known interval. Gibson gave no information on the effect of similar infection intensities on different-sized trees of the same age. Our data suggest that the impact of the same relative level of infection is greater on small than on large trees and, as the level of infection increases, the difference in growth between size classes increases. This tree-size/infection-level relationship, coupled with possible changing infection intensities with time (years) may explain why, in field trials, Gibson noted wide variations in the relationship between defoliation levels and growth rates.

With Armillaria root rot the increment reduction in category II_A did not differ significantly from that in category I_A; however, one-third of the II_A trees were lost as a direct result of infection by *Armillariella*. An increase in girdling beyond 80% therefore appears to reduce tree stability and to increase the possibility of death, rather than further reducing increment in surviving trees. With more than 15% of the potential crop trees in this stand classified as either I_A or II_A, and no control for established *Armillariella* infections, the disease will likely remain significant throughout the rotation (until about 1995).

Armillaria root rot is commonly considered most serious on trees weakened by other causes (12). Indeed the growth reduction on trees affected by both diseases (Site 3) was much greater than the additive effect of the two diseases separately. Yet, from the manner of our tree selection and the small sample sizes, possible predisposing and synergistic effects cannot be clarified.

In comparison to information on decay, mortality, and malformation, there is scant literature quantifying the impact of diseases on forest tree growth. With the use of dendrometer bands we have detected and quantified the impact of various levels of two different diseases on tree diameter growth. Since the time span for data collection was short, changes in intensity of infection did not complicate the results. We were able to determine that the weekly and seasonal patterns of growth had not been altered by disease and that the influence of disease during a year could be characterized early in the growing season. The data allowed us to compare the growth reduction of trees infected with only a foliage disease, only a root rot, or the two in combination. While our data did not indicate inter-relationships between environmental factors, disease, and patterns of tree growth, dendrometer bands could be useful in studying these possible interactions. Such information can be of direct use to the practicing forester and is essential for accurate modelling of forest biomass production in relation to disease.

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