Armillaria – a hidden disease of *Pinus radiata*

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Abstract

An intensive survey of every tree in an apparently healthy unthinned six-year-old second-rotation stand of *Pinus radiata* D. Don in Kaingaroa Forest revealed that many trees with green crowns throughout the 3 ha study area were suffering from Armillaria root disease. Although mortality was only 3%, a further 22% of trees were chronically infected by the disease, and of these 36% were more than 0.5 girdled by infection at the root collar. This study complements unpublished data indicating that appreciable chronic disease is present in second rotation stands throughout this forest, and suggests that a management system may be needed to minimise the impact of the disease.

Introduction

Armillaria species (*A. novae-zelandiae* (Stevenson) Herink and *A. limonea* (Stevenson) Boesewinkel) are responsible for an important root disease in plantations of *Pinus radiata* in New Zealand. Mortality is characteristic mainly of sites cleared of selectively logged indigenous forest where between 20 and 50% of young pines are killed in the first six years after planting (reviewed by Hood, 1989). Since fewer areas of residual indigenous forest are now being converted to *P. radiata* the visual impact of the disease is becoming less dramatic, and many foresters tend to assume that a serious problem no longer exists. However, studies in a central North Island stand have revealed substantial chronic or "symptomless" disease in trees with healthy green crowns (Shaw and Toes, 1977; MacKenzie, 1987). Unpublished data collected by M. MacKenzie and N.M. Self (pers. comm.) have revealed chronic infection in young second-rotation stands of *P. radiata* in Kaingaroa Forest where formerly the disease did not occur (Gilmour, 1954). It was therefore considered desirable to establish a trial to determine the effect of silvicultural management in reducing disease levels in infected stands. This paper presents the results of a detailed survey to map the trial site for incidence and distribution of infection in order to demonstrate the extent of disease in an apparently healthy stand.

Method

Part of a young second-rotation stand of *P. radiata* planted in 1985 was chosen for the trial on a flat, freely-draining, broad, level terrace adjacent to the Rangitaiki River in Compartment 365, Kaingaroa Forest (site index: 27.0m). At age six years the new stand appeared healthy and vigorous, with only trace mortality from *Armillaria* scattered diffusely throughout, which was the basis for site selection. The previous crop, *P. nigra* ssp. *laricio* (Poir.) Maire was high-pruned by age 27 years but apparently never thinned (records of the Forestry Corporation of New Zealand Limited, per P. Painter, R. Fisher, pers. comm.). After clearfelling in 1983 at age 54 years, the slash was burned and the site replanted two years later in lines along the mounds formed by a light "V-blade" ground preparation (i.e. a 50% scraping of the ground area in alternating parallel bands using a bulldozer with V-shaped blade attachment; Fig. 1).

Fig. 1: A typical view in the surveyed stand showing trees with healthy green crowns (stand age, 6.5 years). The trees run in lines along mounds on either side of the "v-bladed" band, centre. (NZFRI 74113)

A rectangular area 195 x 159 m (3.1 ha) containing 2632 trees was subdivided into 20 plots of dimensions 39 x 39.8 m arranged in four rows and five columns. Stocking density averaged 848 ± 30 stems per hectare (plot mean and standard deviation, including the few dead trees), and basal area measured at stand age 6.5 years was 14 ± 2m^2 per hectare (plot mean and standard deviation, unthinned; dead tree contribution insignificant). Aerial photography was used to map trees within each plot before crown closure.

The field survey for *Armillaria* infection was conducted at intervals over a period of 11 months at a stand age between 5.5 and 6.5 years, and was completed prior to any silvicultural treatment. All trees were assessed by exposing the root-collar zone using a short-handled grubber and estimating the extent of girdling by *Armillaria*-caused resinosis (confirmed in each case by the presence of rhizomorphs).

Samples of colonised wood from dead trees were collected for isolation of *Armillaria*. Small wood chips were aseptically cut and plated onto 10% malt agar supplemented with 40 ppm orthophenylphenol (sodium salt) and 100 ppm streptomycin sulphate. Cultures were identified to species using two independent cultural techniques previously described (Hood and Sandberg, 1987) based on: (i) colony morphology under a 24h photoperiod (M. Benjamin, 1983, University of Auckland, unpublished thesis); (ii) compatibility with standard single-basidiospore tester isolates of different *Armillaria* species. Field isolates were also sorted into vegetative compatibility groups by pairing them together on 3% malt agar and noting the presence or absence of mutual incompatibility after three weeks.

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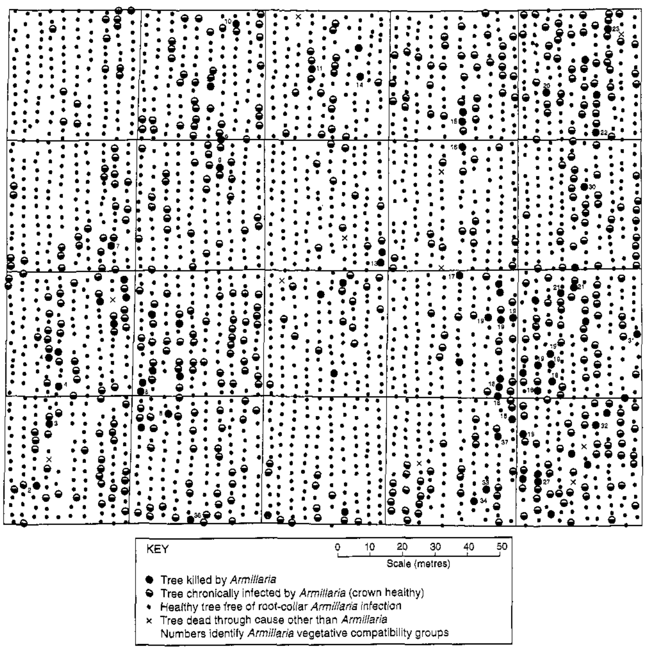

Fig. 2: Map of study area showing distribution of *Armillaria* infection.

Results are presented as a map (Fig. 2) and in Tables 1-3. Statistical methods were used to examine variation in infection across the site (Chi^2 Test, Fisher's Exact Test) and in diameter growth between different infection classes (Least Significant Difference Test). Infection among potential final-crop trees was also considered using data from eight randomly selected plots that were marked out for a thinning to 250 stems per hectare.

TABLE 1 - Incidence of trees infected by *Armillaria* in a 6-year-old second rotation *P. radiata* plantation

Crown condition	Healthy[1]				Dead		Total infected	Total trees
Proportion of root-collar girdled by *Armillaria* infection[2]	0.0	<0.25	0.25-0.5	>0.5	1.0	0.0[3]		
No. trees	1982	215	147	199	79	10	640	2632
Percentage	75	8	6	8	3	<0.5	24	100

1 Excepting infection by *Dothistroma pini* Hulbary in the lower crown
2 Resinosis accompanied by rhizomorphs
3 Includes establishment losses

TABLE 2 - Percentage of trees infected by *Armillaria* in 20 plots ranked in order of increasing infection

Infection percent (individual plot values)[1]	Significance[2]
9, 9, 11	a
12, 13	ab
17	abc
19, 19, 21	bcd
26	cd
27, 28, 28	cde
29, 29, 29	de
39, 39	ef
41, 43	f

1 Includes trees killed by *Armillaria* infection and living trees with chronic infection.
2 Means linked by the same letter subscript are not significantly different ($p > 0.05$; Fisher's Exact Test)

TABLE 3 - Diameter growth compared between levels of infection

Crown condition	Proportion of root-collar girdled by *Armillaria*[2] infection	Mean dbh[3]	Significance[4]
Healthy[1]	0.0	13.8	a
"	<0.25	14.3	a
"	0.25-0.5	14.0	a
"	>0.5	12.8	b
Dead	1.0	2.8	c

1,2 As for Table 1.
3 Least Squares means (stand age: 6.5 years)
4 Means linked by the same letter subscript are not significantly different ($p>0.05$; LSD test)

TABLE 4 - Mean percentage of living trees chronically infected by *Armillaria* in 6- to10-year old second rotation *Pinus radiata* at 24 sites throughout Kaingaroa Forest (data of M. MacKenzie and N.M. Self[1])

First rotation species	No. sites[2]	Proportion of root collar girdled by *Armillaria* infection		
		<0.5[3]	>0.5	Total[4]
P. radiata	5	14	8	22 (5-38)
P. ponderosa P. & C. Lawson	5	4	2	6 (1-20)
P. nigra ssp. *laricio*	5	16	6	21 (3-34)
P. contorta Loud.[5]	4	1	0	1 (0-4)
Pseudotsuga menziesii (Mirb.) Franco	5	14	10	24 (10-42)

1 Presented in unpublished proceedings of the 36th Annual Western International Forest Disease Work Conference, Utah, USA, 1988.
2 One 200-tree offset transect per site.
3 But >0.0 (i.e. trees uninfected at the root collar are excluded).
4 Range of site values presented in brackets (low values not necessarily indicative of safer species, e.g. refer Footnote 5).
5 Small, poorly-grown trees tractor crushed and burned prior to replanting (i.e. *Armillaria* food-base limited).

Results

Armillaria was widespread and common in the study area (Fig. 2, Table 1). Although total mortality was only 3% at age six years, a further 22% of living trees were chronically infected by the disease. Among trees infected by *Armillaria* (killed and still living) 43% were more than 0.5 girdled in the root collar region (Fig. 3). In the eight plots marked out at 250 stems per hectare, 21% of the potential final-crop trees were chronically infected by *Armillaria* (of which 38% were more than 0.5 girdled at the root collar).

Although widespread, *Armillaria* was not evenly distributed and significant differences in percentages of trees infected were found between plots ($p < 0.001$, df = 19, Chi^2 Test). Plot values are given in Table 2. It was also noticeable that infected trees frequently occurred in small linear clusters along planting rows (Fig. 2). Cumulative diameter growth at 6.5 years was significantly less for trees more than 0.5 girdled by *Armillaria* infection than for those with less or no infection (mean DBH: 13 cm, 14 cm, respectively,Table 3).

All *Armillaria* cultures isolated from dead trees were of *A. novae-zelandiae* and belonged to 27 vegetative compatibility groups (Fig. 2). Compatibility groups were confined to single dead trees or distributed over areas up to 25 m across (group 19).

Discussion

Most trees in the surveyed stand were green-crowned and typical of those present in healthy plantations of the same age on good sites in the central North Island (Fig. 1). Nevertheless, appearances were deceiving and chronic Armillaria root disease was found to be widespread within the survey plots in the study area (Fig 2). This result complements data collected during a more general survey by M. MacKenzie and N.M. Self (Table 4 pers. comm.), which suggests that chronic infection is present at significant levels in apparently healthy stands in Kaingaroa Forest. The precise impact of chronic disease needs further investigation but concern appears warranted. There was significantly less diameter growth present on trees more than 0.5 girdled at the root collar (Table 3), a finding previously demonstrated by Shaw

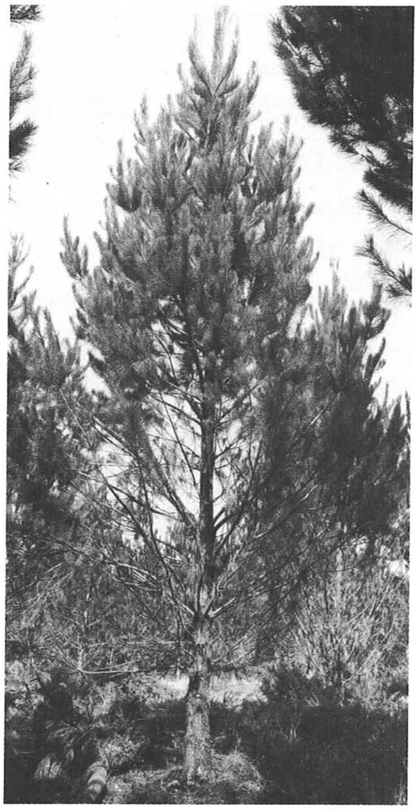

Fig. 3:
(a) (above) An infected tree in the study area carrying a green, healthy crown (apart from some needle loss at the base caused by *Dothistroma pini* Hulbary). The plot has just been thinned. (NZFRI 74115)

(b) (below) Root collar of the tree in (a) exposed to show resinosis and cankering caused by chronic *Armillaria* infection (girdling exceeds 50% in this tree). A rhizomorph is visible across the centimetre scale. (NZFRI 74113)

& Toes (1977). This difference is equivalent to a reduction of 14% basal area per tree. The results of Shaw and Toes (1977) suggest that reduced growth is caused by increased infection rather than the reverse. Infected trees are also prone to windthrow through weakening and breakage just below ground level (H.C. Essenberg, 1988, University of Canterbury, unpublished dissertation). MacKenzie (1987) considered that despite appearances, volume loss from these causes in diseased final crop trees is more important than mortality loss early in the rotation. Stand volume reduction from Armillaria root disease may be even greater if foliage infection by *Dothistroma pini* Hulbary is not adequately controlled (D.E. Etheridge, 1967, New Zealand Forest Research Institute, unpublished report; Shaw and Toes, 1977).

Before afforestation began the Kaingaroa Plateau was once covered in tussock, fern, or scrub, but devoid of trees except for those in a few localised pockets of indigenous forest (Colenso, 1894 pp. 373-5; Ure, 1950; Cowan, 1982; McEwen, 1987; Nicholls, 1990). *Armillaria* apparently invaded the established pine plantations by means of airborne basidiospores carried from nearby natural forest remnants or from further afield. Spores colonised dead trees and stumps in the first plantings, from which infection ultimately spread to living trees in the following crop (Gilmour, 1954). The argument for spore colonisation is supported indirectly by the observed distribution patterns of *Armillaria* colonies (vegetative compatibility groups) which occur in clusters that are small and comparatively numerous (Hood, 1989; Horner, 1991). In the present study minimum colony density was 9 per hectare in a limited sampling from dead trees only (additional colonies may be present in chronically infected trees). Irregular colonisation apparently explains the uneven distribution of infection which was not associated with any obvious factors across the site. However, "V-blading" appears to have induced a linear development of disease (Fig. 2) possibly by facilitating between-tree spread of infection through enhanced root growth along planting mounds, or perhaps by rearranging the primary inoculum into parallel lines before planting.

The incidence of Armillaria root disease may increase in Kaingaroa Forest with the continued long-term cropping of the same susceptible host through successive rotations. Since *P. radiata* will undoubtedly remain the preferred production species it will become necessary to minimise disease levels through appropriate silviculture or by corrective pre-plant ground preparation (e.g. stump removal). It may also be possible to reduce infection by treating stumps with a chemical or biological agent (Yang Li and Hood, 1992). Thinning is likely to influence chronic disease levels by providing additional food bases for existing or new inoculum in the form of freshly cut thinning stumps. Although it would seem desirable to keep such stumps small by thinning early down to the final stocking density, beneficial effects might be offset by any subsequent mortality among already infected residual final-crop trees. The Kaingaroa study area is to be maintained as a trial in which the effect of silviculture on *Armillaria* infection will be monitored. Plots will be thinned at different times (ages seven and/or 12 years) and intensities (250 or 500 stems per hectare), in order to determine the effect of stump size, early or later in the rotation, on disease progress. Controls will consist of plots kept free of thinning stumps (by not thinning or by thinning by whole-tree extraction). The intention is to define a regime on which to base realistic management of this disease.

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