EARLY PATTERNS OF ARMILLARIA ROOT ROT IN NEW ZEALAND PINE PLANTATIONS CONVERTED FROM INDIGENOUS FOREST —

AN ALTERNATIVE INTERPRETATION

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ABSTRACT

Patchy occurrence of root rot in pine plantations aggravates economic loss by removing land from production. On sites of former indigenous forest in the North Island of New Zealand, patches of **Armillaria** root rot develop within the rooting area of former large trees, especially **Beilschmiedia tawa** (A. Cunn.) Benth. et Hook. f. ex Kirk and Podocarpaceae. Seedlings planted near larger infected roots of the old tree die quickly and almost concurrently at and away from the stump. Later a zone of peak mortality progresses successively from the stump outward as the seedling stand is depleted near the stump and as distances between seedlings and infectious main roots away from the stump become greater. An impression of indeterminate, rapid, patch enlargement results which may be misleading. Until the dynamics of patch development are better understood, quantitative prediction of any losses that might accompany aging of the patches should be made with caution.

INTRODUCTION

In many parts of the world *Armillaria* root rot, caused by species of *Armillariella* Karst., has distinctively damaged regenerating forests and especially pine plantations established after removal of native timber. This seems particularly true in New Zealand

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(Shaw and Calderon. 1977; MacKenzie and Shaw, 1977) where disease commonly appears as patches or foci of dead trees during the early life of the plantations, which are usually *Pinus radiata* D.Don. In the first 3 years after planting seedling loss may reach 40% (Beveridge, 1973), creating unproductive openings which reduce yields and increase production costs (Shaw and Calderon, 1977). More needs to be known of the biology of root rot patches around stumps of indigenous old-growth trees. Two views predominate. One regards *Armillaria* root rot as a relatively localised phenomenon associated with a particular infected old tree or stump and its roots, the food base of the fungus (Boyce, 1948; Hepting, 1971). The other predicts that patches enlarge indefinitely beyond the food base of the old root systems (MacKenzie and Shaw, 1977; Pielou, 1965; Shaw *et al.,* 1976; Redfern, 1973).

Knowledge of the characteristics and limits of focus development is necessary for accurate projections of disease loss. This report, largely based on New Zealand indigenous forest converted to pine, further examines the hypothesis that foci or root rot arising at old stumps enlarge radially more or less indefinitely. It also notes the extent to which root rot distribution may be in patches or at random.

METHODS

Data describing the pattern of root rot mortality among planted pine seedlings on sites recently clearfelled of indigenous timber are from a 50 × 50-m plot that had been predominantly tawa (*Beilschmiedia tawa* (A. Cunn.) Bench. et Hook. f. ex Kirk) forest and a 40 × 60-m plot previously predominantly in Podocarpaceae. The plots were established by Shaw and MacKenzie on the Mamaku Plateau at an altitude of 450 m to compare the quality of roots and stumps of different species of indigenous trees as food sources for *Armillariella.* One plot, logged of scattered podocarps about 30 years ago and selected here for high density of tawa, is beside Leslie Road under management of N.Z. Forest Products Ltd. The other, with a formerly high density of podocarps, is 20 km distant on McPherson Road in Horohoro State Forest. Both areas were logged in the summer of 1973. Residual non-commercial trees were clearfelled that winter and burned the following autumn. The plots were laid out in the summer of 1975, cleared of unburned logs and slash, and in July planted with *P. radiata.* Because of the high density of planting (*c.* 1 m × 1 m) the plots were well suited to furnish data about the pattern of development of individual root rot foci.

Mortality from root rot was recorded at 6-month intervals following procedures of MacKenzie and Shaw (1977). After 30 months the plots were thinned by digging alternate trees. Occurrence of disease based on both mortality and root infection of thinnings was recorded by row number and tree number within the row. Locations of stumps more than 10 cm in diameter were mapped from the field and positions of individual pines attacked by *Armillariella* were entered on the maps from the data sheets. Distinctive map symbols were employed for trees recorded at each 6-month interval and for trees found to be infected at thinning.

In the spring of 1978 locations of diseased trees and trees that had died previously were marked in the field by crosses so that disease development to that time could be recorded on aerial photographs. Crosses consisted of two pieces of white venetian blind stripping *c.* 30 cm long, nailed to the top of a 1-m stake.

In the tawa plot, the chronology of root rot mortality among pine seedlings near each of the 20 most-isolated, large, tawa stumps was determined from the maps. Seedlings killed near each stump during each of the five 6-month intervals were tallied into distance classes based on concentric zones 0-2, 2-3.5, and 3.5-5 m out from the centre of each stump. Where two stumps were fairly close but otherwise well isolated the counts were based on two half-circle segments of the three distance zones, each half-circle located on the side of its respective stump away from the interfering neighbour. Sometimes. if the two stumps were well separated, seedlings could be counted on sectors greater than a half-circle. Where three or more stumps interfered, smaller sectors were required, each with its points at a stump but oriented so that its zones were away from interfering stumps.

Similar procedures were applied to the 12 best-spaced podocarp stumps on the podocarp plot.

All values were totalled and converted to an equivalent area basis.

RESULTS AND DISCUSSION

The pattern of distribution of diseased trees was examined from aerial photographs (Fig. 1) and expressed numerically by recording the frequency with which crosses identifying dead trees stood alone or adjacent to others (Table 1). Counts suffered minor error from screening of occasional crosses by intervening pine foliage and from irregularities in placement of crosses resulting from obstacles on the plots.

Dead trees stood alone, in pairs, or adjacent to two to four others (within 1 m) (Table 1). Single trees, or the more numerous paired trees, were assumed to indicate scattered infection associated with either chunks or infected forest debris or with diseased scattered stumps too small to establish root rot foci. Dead trees adjacent to two or more others indicated foci of root rot which were centred on large old stumps or groups of stumps.

Armillariella develops as a saprophyte in woody residues of the indigenous forest and apparently also as a parasite, perthophyte, or epiphyte on tree roots. When trees are felled or die the fungus quickly colonises the cambium of the entire root system (Roth *et al.*, 1977). Thus it is immediately in a position to establish a patch of root rot

TABLE 1—Frequency with which diseased or dead pines are adjacent to others with root rot or occur alone

Dead trees adjacent to subject tree*	Plot			
	1 Tawa		2. Podocarp	
	No.	%	No.	%
0	187	25	91	19
1	257	35	135	27
2	190	26	136	28
3	81	10	80	16
4	29	4	49	10
TOTAL	744	100	491	100

* Dead trees occurring alone or in pairs are interpreted to arise from a limited, scattered food base. All others are regarded as focal.

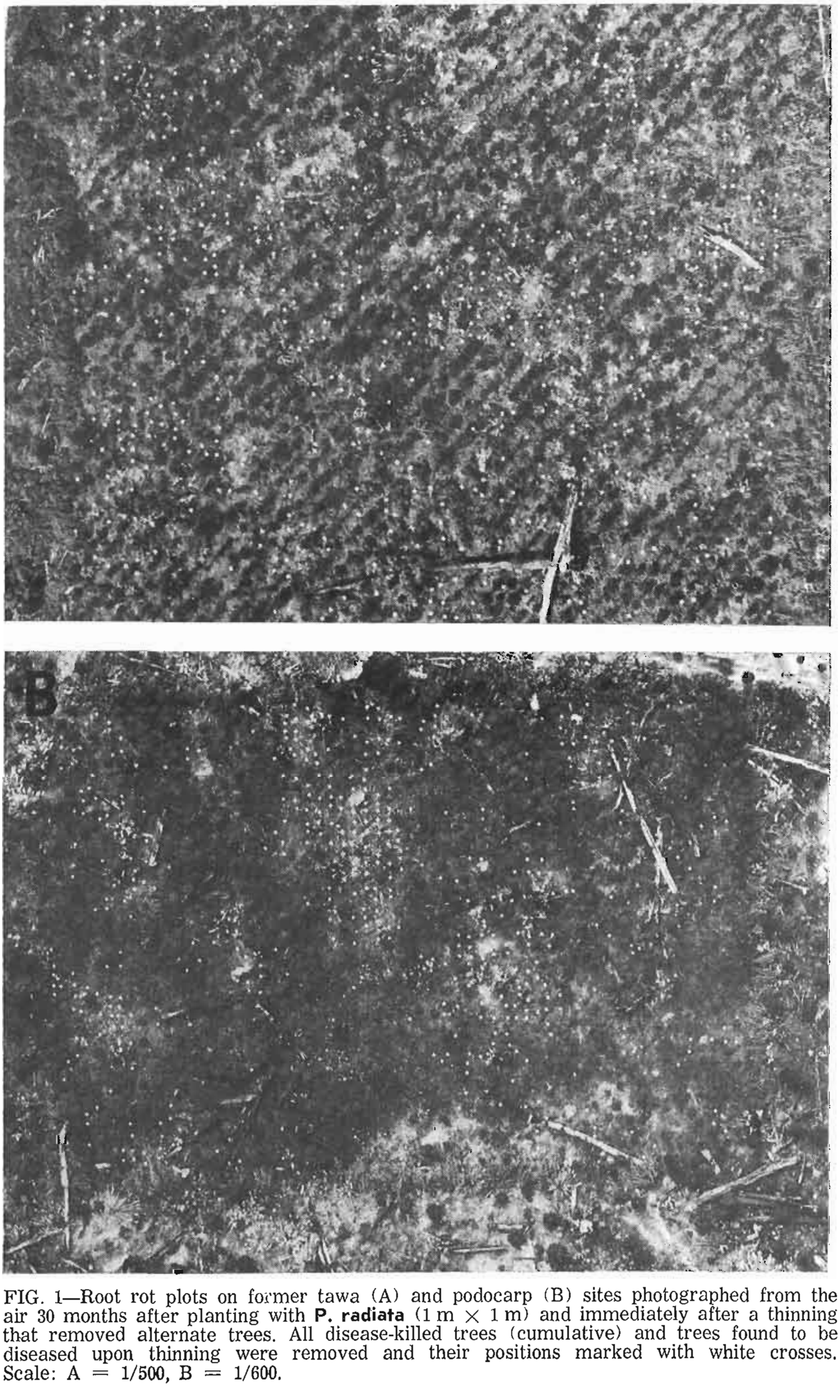

FIG. 1—Root rot plots on former tawa (A) and podocarp (B) sites photographed from the air 30 months after planting with **P. radiata** (1 m × 1 m) and immediately after a thinning that removed alternate trees. All disease-killed trees (cumulative) and trees found to be diseased upon thinning were removed and their positions marked with white crosses. Scale: A = 1/500, B = 1/600.

among seedlings planted through the area occupied by the old roots. This effect was evident on the Mamaku plots within 6 months of planting. After 30 months, 40% and 54% respectively of the 744 and 491 dead trees on the tawa and podocarp plots were adjacent to two or more others in stand-damaging patches of root rot.

Trees killed by scattered inoculum affect the stands somewhat like silvicultural thinning and are much less threatening to productivity of well-stocked plantations during the early years. Through rapid growth the pines become more massive and less easily killed by root rot. They are thus somewhat protected against further damage from inoculum in the rapidly decomposing debris. More persistent inoculum in small stumps may prolong damage a few additional years.

In the stand-depleting patches we have encountered two distinct patterns of mortality. These appear strongly influenced by stocking. Probably other types, or combinations, occur.

In much of the *Pinus ponderosa* Laws. forest of north-western United States where a dense understorey naturally regenerates between the large trees, and the rooting zones of these trees frequently are identifiable as grassy tree-free parks, patches of root rot arise from infected roots at park perimeters after death of infected old trees. These patches enlarge radially more or less continuously through the dense understorey, primarily by root-to-root contact (Shaw *et al.,* 1976; Shaw, 1979). By contrast, in New Zealand *P. radiata* seedlings are planted uniformly within as well as between rooting areas of former indigenous timber, and root rot patches appear to enlarge radially from near the old stump. Whether spread occurs from one widely spaced (by contrast with natural regeneration) planted seedling to the next, either within or beyond the rooting zone of the old tree, is uncertain. Any such spread seems limited, if it occurs.

Within measured patches on our plots 38%, 30%, and 24% respectively of seedlings at distances of 0-2, 2-3.5, and 3.5-5 m were dead after 30 months, paralleling values of 32%, 18%, and 10% found by MacKenzie and Shaw (1977) in an earlier plot on the Mamaku Plateau. Results from these plots provided further insight on patch growth and suggest an alternative or variant to the usual interpretation of indefinite radial enlargement.

The root rot patch can be regarded as potentially comprising two parts: an inner part overlying the old indigenous root system and an outer part beyond. MacKenzie and Shaw (1977) interpreted the smaller mortality percentages occurring away from the stumps (but still within the inner part) to indicate ". . . that mortality will continue in radially expanding infection centres [beyond the inner part] (cf. Redfern, 1973), putting more ground out of production." While more trees surely will die, and most of them necessarily will be away from the stumps, as numbers there are greater, it seems less certain that the area of the patch will actually increase in size to form an outer infected part, at least at the rate that would be implied by previous interpretation of either the MacKenzie-Shaw data or ours.

The above percentages, which demonstrate decreasing mortality with increasing distance from the stump, were presumably generated mostly from close association between roots of pine seedlings and the major infected roots of the old stump (*see* Filip, 1979; Russell, 1978). In the congested environment of large roots near the stumps, seedling proximity and therefore exposure to inoculum is maximised and early mortality is conspicuous. Concurrent, more scattered, but numerically greater mortality away from the stump is less striking. Proximity to large roots and exposure to infection decrease with distance from the stump as spaces between the larger infectious roots become wider. Higher frequencies (proportionately) of mortality away from the stump therefore are delayed until these spaces are bridged by growth of seedling roots or by rhizomorphs. Disease appeared to peak (in respect of number of seedlings per unit area of ground) during the first and second, second and third, and third to fifth periods respectively for the inner, middle, and outer zones (Table 2). On this basis there was a low wave of mortality moving outward to the limits of the old root system which, taken at face value, suggests indefinite patch enlargement.

TABLE 2—Distribution of dead and diseased pine seedlings around 20 large tawa and 12 large podocarp stumps colonised by **Armillariella**

Months since planting	Distance from stumps						Total No.
	0-2 m		2-3.5 m		3.5-5 m		
	No.*	%†	No.	%	No.	%	
6	7	50 ‡	4	28	3	22	14
12	16	47	11	33	7	20	34
18	11	37	9	30	10	33	30
24	4	36	3	28	4	36	11
30	2	40	1	20	2	40	5
TOTAL	40		28		26		94

* Dead and diseased seedlings/100 m^2 among 313, 575, and 1021 respectively, planted on segments of concentric sampling zones totalling 297, 611, and 944 m^2.

† Percentage mortality among the three sampling zones, adjusted to an equivalent area for each zone.

‡ Vertical lines emphasise periods of peak mortality for each distance, not statistical significance.

While percentage mortality at the outset was very high near the stump, seedlings were dying concurrently, though not at a uniform rate, over the entire inner part of the patch (area occupied by old roots). This was evident at all sampling intervals (Table 2). For the cumulative 30-month period differences in mortality among the three distances from the stump were not significant when tested by χ^2 (2 d.f., $P > 0.05$). The important variations among distances are those at the shorter time intervals.

Genesis of present mortality is poorly understood partly because disease is rarely observed in the indigenous forest. Roots of living tawa trees which when dead would be excellent food bases for *Armillariella,* bear epiphytic rhizomorphs and superficial lesions that suggest interaction with the fungus. However, even if living tawa are not infected there still appears, during forest conversion under management, to be ample time between felling of the indigenous timber and planting pines (approximately 18 months on our plots) to allow entire old-growth root systems to become colonised by a former epiphyte. This being so, the limits of the tawa root system rather than a conspicuous display of dead pines near the stump would define the real size of the focus as against its apparent size.

The mortality rate in all zones declined rapidly after the first 18 months. This decline would have resulted in part from increased tolerance of the pines with age and to a minor degree from decreased numbers of trees available for infection, especially nearer the stump. At one stump, only 2 of 14 trees remained alive after 30 months. Further decline probably results from a decrease in inoculum at greater distances from the stumps as the smaller roots of the old host decompose, and competition from root-inhabiting saprophytes increases. Such decline is reported by MacKenzie and Shaw (1977).

From these trends it seems uncertain that the patch will develop beyond the old root zone to form an outer part to the focus. If enlargement does occur it will be by different means and therefore probably at a different rate from that of the initial development. Possible means include radial growth of rhizomorphs (Redfern, 1973) or growth of roots of surrounding pines back into the patch to contact old inoculum or roots of recently killed trees or infected survivors. As yet we have little evidence from New Zealand plantations that these mechanisms of contagion are seriously enlarging patches of mortality beyond the limits of the old root systems. Until details of patch enlargement are more fully known, projections of expected damage based on initial loss should be tentative. Seriousness of early damage on *Armillariella* sites appears particularly to depend on abundance in the indigenous forest of species, especially tawa, that are good food sources for *Armillariella* in its saprophytic state.

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