CHANGES WITHIN TREE CROWNS FOLLOWING THINNING OF YOUNG DOUGLAS FIR INFECTED BY *PHAEOCRYPTOPUS GAEUMANNII*

I. A. HOOD and C. J. SANDBERG

Forest Research Institute. New Zealand Forest Service, Rotorua

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ABSTRACT

A survey was carried out of tree crowns in a 22-year-old stand of Douglas fir (**Pseudotsuga menziesii** (Mirb.) Franco) in order to study changes following thinning five years earlier. Thinning to 220 and 740 stems/ha did not increase foliage retention or needle density, and had, at most, only a slight effect on mean infection of **Phaeocryptopus gaeumannii** (Rohde) Petrak, which was not less than 79% at different crown levels. In the lower crown region of unthinned trees ninth whorl branches retained needles longer, but showed less shoot extension over the last two years, than equivalent, unsuppressed branches of thinned trees. Thinned trees developed deeper crowns. An adjacent, 24-year-old stand thinned to 220 stems/ha 12 years previously still retained a high infection (more than 96%), and foliage retention and density were no greater than on trees of the same stocking in the more recently thinned stand.

INTRODUCTION

Thinning has been advocated for different reasons as a means of correcting the decline in stands of Douglas fir (*Pseudotsuga menziesii* (Mirb.) Franco) attributed to the Swiss needle cast fungus *Phaeocryptopus gaeumannii* (Rhode) Petrak (e.g. Merkle, 1950-1951; Stefanelli, 1963; Strittmatter, 1974; Cameron *et al.,* 1978). Merkle (1950-1951), Murray (1952-54), and Strittmatter (1974) have all noted a general recovery in the appearance of unhealthy stands some years after thinning. Murray also observed that although *P. gaeumannii* was almost ubiquitous it was no longer regarded as serious. No other relevant material appears to be published. *P. gaeumannii* was first found within Kaingaroa Forest, in the central North Island, in 1960 (unpublished records) and older stands of Douglas fir began to show a decline in growth within the following 10 years (Beekhuis, 1978; Wooff, 1978). This article reports the results of a survey carried out during the winter of 1977 in a younger, infected stand in Kaingaroa Forest in order to investigate changes within tree crowns following thinning that might reduce or counter the effect of the needle parasite and so offset potential growth decline. Measurements were made of crown depth, needle retention, needle density, needle length, branch internode length, and infection of *P. gaeumannii.* Root systems were not studied even though they may also respond to thinning. Use was made of a thinning trial established by forest staff and an adjacent seed stand of similar age which had been thinned some years earlier. The trial is being monitored annually for growth (C. J. Mountfort, pers. comm.) and any significant long term increases in diameter and volume as a result of thinning will eventually be evident. For this reason measurements of height and diameter were made only to indicate the sizes of trees used.

MATERIALS AND METHODS

The thinning trial and seed stand are situated within an area in compartment 1279 not more than 1.1 km across on undulating country on a well drained, pumice soil. Different seed origins were used for the two stands. The thinning trial is laid out in a randomised block design with three replications per treatment. Three treatments were selected for the survey, consisting of those plots with stocking levels of 220 stems/ha, 740 stems/ha, and unthinned, control plots (original stocking, 2990 stems/ha). Each plot in the trial occupies 0.10 ha, not including a 10-m wide plot surround. Three further randomly sited plots were sampled in the seed stand which was stocked at 220 stems/ha. At the centre of each plot, 8 of the largest diameter trees at a relative spacing equivalent to 220 stems/ha were selected, regardless of the stocking level of the plot itself, in order to make a fair comparison between treatments. A total of 96 trees from 9 trial stand and 3 seed stand plots were evaluated. At the time of this survey the thinning trial stand was aged 22 years (thinned at age 17 years) and the seed stand 24 years (thinned at ages 7, 11 and 12 years; see Whiteside *et al.,* 1977).

On each tree measurements were made of d.b.h., tree height, and height to the base of the green crown. The green crown base was defined as midway between the lowest foliage of the lowest green whorl and the lowest whorl with two green branches. Heights were determined by climbing with a pole and measuring tape and a clinometer was used to indicate the horizontal when measuring green crown base.

In order to evaluate foliage and infection, shoot samples were taken from all survey trees at the 5th, 7th, 9th and 11th stem nodes, except that only one plot of each treatment was sampled at the 7th whorl (Table 1). At each node secondary shoots of ages 0-1, 1-2, 2-3, and 3-4 years were cut from one side (randomly chosen) of the more dominant primary branch most closely orientated to a direction randomly preselected. The portion of each year's growth directly attached to the primary branch stem was chosen. With few exceptions there was little difficulty identifying the symmetrical nodal and internodal annual growth patterns on the stem and branches of each tree, and ages were determined by carefully counting the correct number of internodes out along each

TABLE 1—Numbers of shoots sampled

Stocking (stems/ha)		Whorl 5	7[1]	9	11
Trial	Unthinned	22-24	7-8	9-20	0-3
	740	20-24	8	19-23	10-15
	220	21-24	7-8	21-24	23-24
Seed Stand	220	17-24	0	20-23	20-22

[1] one replication, only.

branch from the trunk. Alternative shoots were occasionally selected if severe rubbing damage (cf. Merkle. 1950-1951) had occurred where crowns of adjacent trees were in contact.

Infection on 1-2 and 2-3 year old secondary shoots was measured under a stereo-microscope by counting 50 needles per shoot and calculating the percentage bearing pseudothecia of *P. gaeumannii.* Infection was not measured on 0-1 year old needles because pseudothecia were imperfectly developed at the time of the survey. To determine needle retention, counts were made of all needles and scars from one or more spiral sets along the full internode length of each of the four age classes. Needle density was found by counting the number of retained needles along a 3 cm (0-1 year) or 6 cm (other ages) length of stem spanning the midpoint of each internode. Lengths of internodes and needles (one from the centre of each internode) were measured directly.

Trial data from the 5th and 9th whorls were examined by means of separate hierarchic analyses of varience, and t tests were used to compare trial and seed stand data for plots thinned to 220 stems/ha. Analyses of variance were not conducted for 7th and 11th whorl data due to the shortage of material (caused in the 11th whorl by suppression in unthinned plots, Table 1). Data were not transformed before analyses.

RESULTS

Thinning had a pronounced effect on crown depth, with lower stocking intensities leading to deeper crowns (Table 2). In the heavily thinned seed stand green crown bases were, on average, only 21% of tree height above the ground. Differences in stocking level among trial trees accounted for 57, 80, and 80% of the variation, respectively, in crown depth (m), crown depth (%), and height of green crown base.

All trees were very heavily infected by *P. gaeumannii* regardless of thinning intensity (Table 3). Trees thinned to 220 stems/ha showed only slightly reduced infection of 2-3 year old foliage in the 5th whorl. In the lower crown smaller pseudothecia tended to occur more on shaded foliage from unthinned trees than on needles from thinned plots. Thinning had a greater effect on other shoot variables, particularly lower in the

TABLE 2—Treatment means for whole tree variables

Stocking (stems/ha)		Number trees	d.b.h. (cm)	height (m)	Crown depth (m)	Crown depth (% tree height)	Height of green crown base (m)
Trial	Unthinned	24	25.3	20.8	9.7	47	11.1
	740	24	27.7	20.4	11.4	56	9.0
	220	24	28.3	19.7	12.8	64	7.0
Seed Stand	220	24	40.4	21.2	16.8	79	4.4
Significance of between-stocking differences		Within trial (anal. of var.)			**	***	**
		Trial (220 only) v. seed stand (t test)			***	***	***

ns no significant difference (probability > 0.05)
* probability of no difference ≦ 0.05
** probability of no difference ≦ 0.01
*** probability of no difference ≦ 0.001

TABLE 3—Shoot sample treatment means by whorl and stocking level
(Trial stand, 5th and 9th whorls, only)

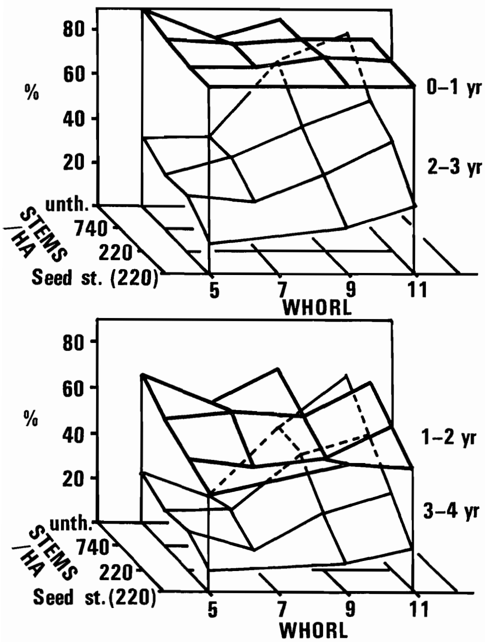
Whorl		5			9		
Stocking (stems/ha)		Unthinned	740	220	Unthinned	740	220
Infection %	1-2 years		98			92	
	2-3 years	100a	99a	79		97	
Needle retention %	0-1 yr		86			87	
	1-2 yr	66a	57ab	49b		59	
	2-3 yr		27		66	47a	34a
	3-4 yr		18		43a	41a	25
Needle density/cm	0-1 yr		16			18	
	1-2 yr		11			12	
	2-3 yr		5		14	9a	8a
	3-4 yr		4			7	
Internode length mm	0-1 yr		213		51	104a	145a
	1-2 yr		229		101	149a	154a
	2-3 yr		237			171	
	3-4 yr		226			185	
Needle length mm	0-1 yr		28			25	
	1-2 yr		27			26	

Within each age class values not linked by a common letter are significantly different at the 5% level (Least Significant Differences test); where there were no significant differences, mean values for all three treatments have been given.

crown. At the 9th whorl, foliage was retained longer on unthinned trees (Table 3; Fig. 1) and mean needle density was greater on 2-3 year old shoots at the same stocking. Mean internode length values of younger shoots were smallest in unthinned plots at the 9th whorl (Table 3; Fig. 2), and some unthinned trees had, in fact, stopped producing new shoot growth in parts of the lower crown. On 5th whorl branches, in the upper crown, 1-2 year old needles had been shed somewhat more by heavily thinned trees, although needle densities were not significantly different between stocking levels. In circumstances where thinning had a significant effect, variance components for different shoot parameters ranged between 39 and 88% (between trees), 0 and 5% (between plots), and 12 and 57% (between thinning treatments).

Trees in the seed stand retained significantly less foliage on longer internodes than trees of the same stocking in the trial stand (Table 4; Figs. 1, 2). Foliage was heavily infected in all whorls of both stands (means more than 90%, except for the lower infection, 79%, of 2-3 year old foliage in 5th (and 7th) whorls of the trial stand, 220 stems/ha only).

In addition to variation with stocking intensity, shoots also showed changes with crown position and age (Fig. 3). Needle retention and density values were both greater lower in the crown, especially so for older foliage. As expected, older shoots had less foliage. Also expected was the result that shoots of the same age were longer, higher in the crown. There was also a tendency for younger shoots to be shorter at any given crown level, although 7th whorl, 3-4 year old shoots behaved somewhat anomalously. Like shoots, needles were longer at higher levels in the crown. However, there appeared



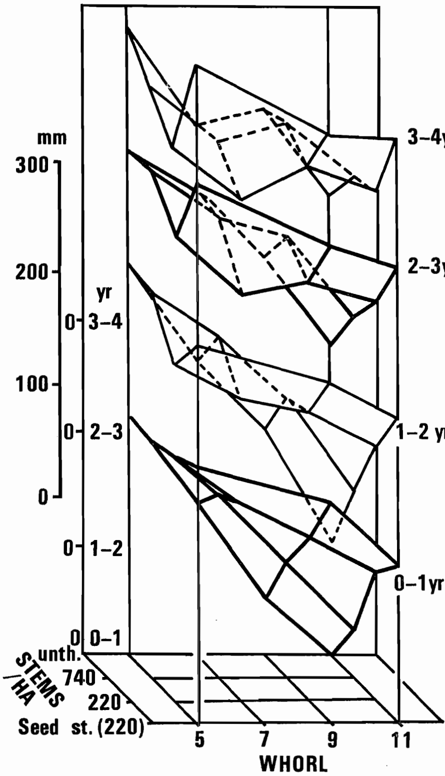


FIG. 1 (left)—Mean values of needle retention (%) by whorl, stocking and age class.

FIG. 2 (right)—Mean values of internode length (mm) by whorl, stocking and age class. (exploded upwards for clarity, necessitating the use of a sliding scale).

to be a tendency for older needles to be slightly shorter than younger ones. Infection percentage was little affected by foliage age or crown position and was high in all trees.

DISCUSSION

Thinning had little practical effect on percentage infection, using presence of pseudothecia as the infection indicator. The lowest mean infection found was not less than 79% (Table 3; 2-3 year, 220 stems/ha, upper crown), and even then younger foliage and foliage lower in the crowns of the same trees was as heavily infected as trees of other thinning treatments. Foliage on trees of the seed stand (also 220 stems/ha) remained heavily infected (more than 96%) 12 years after being last thinned regardless of age or position in the crown. Work carried out with trees of seed sources other than the two used here suggests that such high infection levels are not uncommon. In addition. Chen (1972) also found similar infection levels on some foliage, at least, and Rohde (1937) observed practically all needles except those of the current set to have ascocarps. Use of the stereo microscope increases the reliability with which infected needles are determined.

TABLE 4—Means of observations on shoots in trial* (T) and seed (S) stands, compared by whorl and age class

Variable	Age class (years)	Whorl 5 T	5 M	5 S		Whorl 9 T	9 M	9 S		Whorl 11 T	11 M	11 S	
Infection (%)	1-2		96		ns		98		ns		94		ns
	2-3	79		99	*		97		ns		99		ns
Needle retention (%)	0-1		83		ns		86		ns		85		ns
	1-2		47		ns		53		ns		59		ns
	2-3	25		14	*	34		21	*	50		30	**
	3-4		13		ns	25		13	*	34		20	*
Needle density (needles/cm)	0-1		16		ns		17		ns		17		ns
	1-2		10		ns		11		ns		12		ns
	2-3	5		2	**	8		4	**	10		6	*
	3-4		3		ns	6		3	*	7		4	*
Internode length (mm)	0-1		222		ns	144		195	***	114		139	*
	1-2	198		234	**	154		200	***	124		168	**
	2-3	212		280	***	170		222	***	153		202	***
	3-4	190		288	***	173		220	**	152		218	***
Needle length (mm)	0-1		27		ns		27		ns		26		ns
	1-2		26		ns		26		ns		25		ns

* 220 stems/ha, only; t test, significance code as for Table 2; where values were not significantly different they have been given as means (column M).

Thinned trees developed deeper crowns (cf. Fenton, 1967). This was the most pronounced effect of thinning observed and should contribute considerably towards increasing tree photosynthate. Since the extra crown length on thinned trees already represented extra foliage mass, it was not used for sampling for comparing thinning treatments. On unthinned trees, numerous branches had died from suppression at the 11th whorl, and to a lesser extent at whorls immediately above, and these were ignored. Live 9th whorl branches in this shaded, lower-crown region displayed two opposing tendencies, one towards growth reduction, and even cessation, of youngest shoots, and the other towards a longer retention of needles. However. the contribution of these older needles to total tree photosynthate under low light intensities would be minimal (Woodman, 1976).

Although foliage in the upper crown was well retained on long, vigorous internodes during the first year, when still photosynthetically most efficient, needle retention and density both steadily decreased thereafter (Fig. 3). This suggests that exposure to an environment of higher light intensity or lower humidity may be detrimental to foliage heavily infected by *P. gaeumannii*. Silver (1962) found that greater needle densities tended to occur in the upper crowns of 80-year-old trees of sizes comparable to those used here, stocked at 150 stems/acre (370 stems/ha) in British Columbia. Such a tendency was not found at the Kaingaroa trial, and densities of older needles were generally lower than in the British Columbian trees. These differences may be caused by the heavy infection with *P. gaeumannii* of trees at Kaingaroa growing outside their natural range. Greater needle retention can be observed on Douglas fir growing in

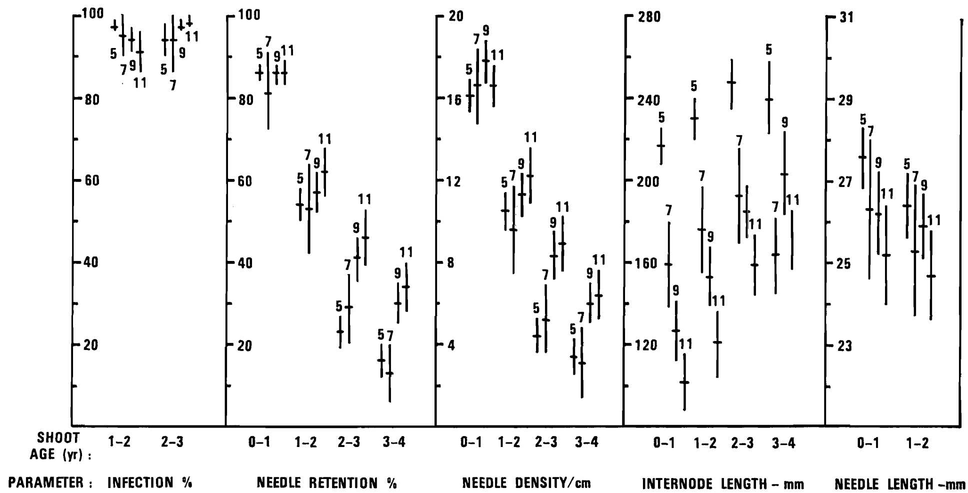


FIG. 3—Shoot sample means and 95% confidence limits, by whorl and age class (includes trial and seed stand data; whorl numbers are indicated).

parts of the South Island where *P. gaeumannii* has not yet been found (Hood and Wilcox, 1971, unpubl.; Kay, 1978). In Fig. 3 means of lower crown, shoot data are to some extent weighted towards heavier thinning. However, use of unweighted values would, if anything. simply enhance existing trends. Combined means in other tables and figures are not affected in this way, although separate treatment means were derived from different shoot numbers. This partially explains the relative shortness of 7th whorl, 3-4 year internodes shown in Fig. 3.

Another treatment effect became apparent during the course of the survey, but was not measured. In the lower crown region of unthinned trees larger (but declining) branches emerged directly at each node while smaller branches of the same year's growth cycle arose from the upper half of the internode beneath. In thinned plots these internodal branches tended to be nearly as large as the nodal branches. Consequently it appears that thinning may lead to a greater number of dominant, vigorous branches per whorl, and hence to a greater contribution to tree assimilation. During the survey, sampling was made from these larger branches.

Whiteside *et al.* (1977) made the observation that needle cast disease in the seed stand was less severe than is usual (in older stands) in Kaingaroa Forest and attributed this to the early, heavy thinning it had received. Results here indicate that the general healthy appearance of this seed stand is not caused by an increased needle retention but by other factors, such as very deep crowns, and perhaps green foliage colour, which is a difficult parameter to measure. It is now clear that this stand is heavily infected by *P. gaeumannii,* and therefore improved needle retention should not necessarily be expected. Despite low retention values for older foliage, all trees in the trial also still looked generally green and healthy, and light intensities were very low beneath the unthinned plots. This healthy condition should continue to be maintained in the plots that have been thinned, despite infection by *P. gaeumannii.*

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