EFFECTS OF THINNING ON CROWN STRUCTURE IN RADIATA PINE

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ABSTRACT

Plots in a randomised block experiment in a 15-year-old plantation of radiata pine (**Pinus radiata** D. Don) of nominal stocking 1700 stems/ha and basal area approximately 40 m^2/ha, were thinned mainly from below to 11, 18, 23 and 28 m^2/ha respectively. Each plot was again thinned 2, 5 and 8 years later to its prescribed lower basal area. Plots given a single light thinning at age 20 years to maintain stand hygiene were used as control.

Total tree height, mean stem internode length and number of green branches per whorl were the only variables of the eleven sampled to be unaffected by treatment. Thinning caused a significant increase in branch diameter particularly in the upper mid-crown, corresponding to 50-80% of total tree height, and altered the proportion of branches in the $<$ 1-cm and 3- to 5-cm diameter classes. These proportions decreased and increased respectively with increase in the severity of thinning.

The relationship between cross-sectional area of the bole at the green crown base and total branch cross-sectional area within the crown is shown to be linear and independent of thinning.

INTRODUCTION

Despite the commercial importance of radiata pine (*Pinus radiata* D. Don) and the fact that thinning is one of the silvicultural treatments having a major effect on the development of trees, major studies in Australia and New Zealand have centred on the effects of thinning on stem growth and wood properties, or on crown dimensions, but not on the effects on stem and crown together.

This study examines some effects of thinning on crown structure in radiata pine. Subsequent papers will deal with effects on foliage distribution and biomass, stem form, wood properties and their interrelationships.

MATERIALS AND METHODS

Material for the study was sampled from a thinning experiment located in Compartment 68 of Green Hills State Forest near Tumut on the Southern Tablelands of New South Wales. The experiment and forest area have been described in detail

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by Shepherd and Forrest (1973). The site is uniform and gently sloping. The soil is a red loamy clay derived from weathered granites and is adequately drained. Nutrient availability is ample to support high quality plantations (Shepherd, 1967).

The experimental area was planted with 1/0 radiata pine seedlings in 1947 at a nominal spacing of 2.4 m × 2.4 m (1736 stems/ha). The seedlings used were from seed collected from silvicultural thinnings in older plantations, so wide genetic variability is retained. All trees were pruned to 3 m in 1956 and the best (at 400 trees/ha) were pruned to 6 m by 1960. The compartment was thinned for the first time in 1962 at age 15 years and this was a commercial thinning.

The experiment is a compact randomised block design comprising six treatments each having four replications. Treatment plots are 0.25 ha square and each contains a 0.1-ha measured sub-plot. The experimental treatments were planned to allow examination of the widest possible range of stand density conditions, the stand density of individual treatment plots being maintained within a narrow range by regular thinning. The basal area limits for each treatment are given in Table 1.

The experiment was established in 1962 at the time of the first commercial thinning of the compartment, when plots were thinned, mainly from below, to the prescribed lower basal area limits. All plots were rethinned to their lower limits in 1964 and again in 1967. The control plots were thinned lightly in 1967 (b.a. 53.5 m^2/ha) to forstall excessive mortality and to maintain stand hygiene. The experiment was thinned for the fourth time in June 1970 when the tree material used in this study was gathered. The tallest trees (50 trees/ha) then had mean height of 28 m.

A total sample of 50 trees was estimated to be adequate to represent the various tree and growth parameters to be studied. Treatment 2 of the experiment, which overlapped Treatments 1 and 3, was excluded from this study because available growth data and experience indicated its inclusion would add little to the study. Also, two replicates of the minimally thinned Treatment 6 were discarded because severe wind damage had occurred. The numbers of trees remaining in measured sub-plots ranged from nine to seventy-three. For statistical reasons a uniform proportion (10%) rather than a uniform number of trees per sub-plot was sampled at random but a minimum of two and a maximum of six trees per sub-plot were specified. Final totals of 8, 8, 12, 16 and 12 trees were sampled from Treatments 1, 3, 4, 5 and 6 respectively.

The selection of sample trees was based on the diameter at breast height over bark (d.b.h.o.b.) in 1962 of trees still standing in June 1970. The trees in each plot were arranged in descending order of d.b.h.o.b. and stratified into groups of equal size, the number of groups depending on the number of trees required per plot (Wolski, 1965). One sample tree and two reserve trees were then selected at random from each group. The sample trees were inspected in the field in June 1970 and those with severe defects (double or multiple leaders, crown or stem damage, severe leans or sweeps) were replaced by reserve trees. A total of 10 trees was replaced due to defect. An additional six trees were replaced because the N.S.W. Forestry Commission considered their removal was silviculturally undesirable because the experiment was to be continued beyond 1970. The final sample is representative of the whole population prior to thinning in 1970 (age 23 years).

Sampling was undertaken in July and August, 1970. Growth of radiata pine is

TABLE 1—Thinning history

Treatment	1	3	4	5	6
Height — age 15	21.3	21.0	21.6	21.9	21.3
Height — age 23	28.2	28.0	28.5	28.6	28.0
Nominal b.a. limits	18 ⟶ 11	25 ⟶ 18	30 ⟶ 23	35 ⟶ 28	Control*
Actual b.a. limits†					
1st thinning — age 15	40.0 → 11.5 (1404) (257)	38.1 → 18.4 (1386) (489)	42.0 → 23.0 (1394) (596)	42.3 → 27.6 (1421) (759)	39.7 (1347)
2nd thinning — age 17	16.5 → 11.5 (257) (163)	24.6 → 18.4 (489) (336)	29.6 → 23.0 (596) (420)	33.8 → 27.6 (759) (556)	45.7 (1320)
3rd thinning — age 20	17.7 → 12.4 (163) (106)	26.9 → 18.6 (336) (213)	32.1 → 23.2 (420) (267)	36.3 → 27.8 (556) (383)	53.5 → 41.4* (1312) (699)
4th thinning — age 23	17.4 → (106)	25.7 → (213)	31.7 → (267)	35.6 → (383)	46.0 (699)
Mean d.b.h.o.b. (cm) — age 23:					
Before thinning	46.0	39.2	38.5	34.3	28.7
Thinnings	45.5	38.5	39.5	34.0	31.6
After thinning	46.1	39.3	38.3	34.3	28.9

Height is stand mean height (m); basal area limits are in m^2/ha

* Thinned at age 20 years to maintain stand hygiene

† Stocking in stems/ha shown in parentheses

minimal during these months in the Tumut District and may be negligible. Before felling, the d.b.h.o.b. of each sample tree was measured and the north point was marked on each bole at breast height. After felling, any broken stem tips were reconstructed and the following parameters measured: total height (m); height from ground to the lowest green whorl (defined as the lowest whorl having a minimum of two live branches); diameter of stem overbark immediately below the lowest green whorl (cm); and diameter of each branch in each green whorl, branch diameter (cm) being measured at a distance of 5 cm from the junction of the branch with the stem. Crown width was not measured because previous experience suggested that large errors would be likely, particularly in the control and lightly thinned treatments.

The tree, crown and branch data were screened using the BASTATS program (Sokal and Rohlf, 1969) which demonstrated the desirability of logarithmically transforming most data to fulfil requirements for analysis of variance. However, the number of green whorls per tree and crown length ratio (ratio of green crown length to total height of tree) required a square root and arcsin transformation respectively. Crown length and the number of green branches per tree were left untransformed.

Separate analyses using Bartlett's test and the F-max test (Sokal and Rohlf, 1969) demonstrated homogeneity of variances, so the *a priori* test described by Sokal and Rohlf (p. 226) was used to test differences between treatment means of the individual crown and branch variables. Treatment combinations tested involved groups of 2, 3 and 4 consecutive treatments respectively. The hypothesis examined was that for each variable, the treatment means grade in value from the most heavily thinned treatment to the least thinned.

RESULTS

Eight of the 11 variables measured were significantly affected by thinning (Table 2). Total height, frequency of green whorls and numbers of green branches per whorl appear independent of thinning. Regressions of green crown length on stem d.b.h.o.b.

TABLE 2—Effect of thinning (treatments 1 - 6) on crown and branch variables*

Variable	Transformation	1	3	4	5	6	
Total height (m)	$\log_e$	28.2	28.0	28.5	28.6	28.0	N.S.
Ht to lowest green whorl (m)	$\log_e$	6.7	7.3	8.3	9.9	13.5	***
Crown length (m)	—	21.5	20.7	20.2	18.5	14.5	***
Crown length ratio	arcsin	0.76	0.74	0.71	0.64	0.52	***
Numbers of :							
Green whorls/tree	sq. root	41.9	46.2	44.3	36.3	32.9	**
Green whorls/m crown length	$\log_e$	2.0	2.2	2.2	2.0	2.3	N.S.
Green branches/tree	—	205	231	220	184	164	***
Green branches/whorl	$\log_e$	4.9	5.1	5.0	5.0	5.0	N.S.
Mean branch diameter (cm)†	$\log_e$	2.2	1.9	1.9	1.7	1.6	**
Mean branch sectional area (cm^2)†	$\log_e$	5.5	3.9	4.0	3.3	2.7	***
Branch sectional area/tree (cm^2)†	$\log_e$	1110	950	885	590	430	***

* Figures given are the equivalents in original units of the means of the transformed variables. Values underscored are not significantly different ($p = 0.05$).

† Branch diameter measured 5 cm from the junction with the stem.

N.S. = not significant; ** = $p < 0.01$; *** = $p < 0.001$.

indicate a difference in slope and intercept between Treatment 5 and the other treatments (Table 3), but this results mainly from unusually short crowns in the smallest sample trees of Treatment 5. The regressions for Treatments 1, 3 and 4 are similar in both slope and intercept, while Treatment 6 has a similar slope but significantly smaller intercept.

TABLE 3—Linear regression coefficients relating green crown length (m) and tree d.b.h.o.b. (cm)

Treatment	b	se_b	a	r	
1	0.440	± 0.348	1.385	0.46	N.S.
3	0.462	± 0.181	1.345	0.72	*
4	0.300	± 0.123	1.903	0.61	*
5	1.164	± 0.314	− 1.187	0.70	**
6	0.479	± 0.121	1.032	0.78	**
Combined data	0.786	± 0.090	0.095	0.77	***

N.S. = non significant; * = $p < 0.05$; ** = $p < 0.01$; *** = $p < 0.001$.

Fig. 1 shows the pattern of branch development in the green crown. Branch diameter increases basipetally to approximately 60% of total tree height and then is more uniform. Branches low in the crown of trees from Treatment 6 appear to have greater diameter because one tree was an atypical "wolf" tree. The effect of thinning is most marked in the upper mid-crown, corresponding to 50-80% of total tree height, where branch diameter increases significantly with decreasing stand density.

The distribution of branches by diameter class differs with thinning treatment (Fig. 2). The proportion of branches less than 1 cm in diameter tends to increase with increase in stand density whereas that of branches 3 cm and larger tends to decrease. The 1- and 2-cm size classes are little affected by treatment.

The relationship between cross-sectional area of the bole at the base of the green crown and the total cross-sectional area of branches in the crown is linear and is independent of stand density (Fig. 3).

DISCUSSION

It has been demonstrated elsewhere for many tree species, and confirmed here for radiata pine, that stand density has a negligible effect on total height growth. This study shows also a negligible effect of stand density on branch internode length and on the number of branches per whorl within the green crown of radiata pine. Apparently factors contributing to nodal elongation or axial bud formation are not influenced by thinning or are not limiting under the study conditions, even at extremes of stand density. This is consistent also with the view that both parameters are under strong genetic control (Fielding, 1960; Forrest and Ovington, 1970). However thinning had marked effects (more so under the lighter treatments) on other variables, particularly crown length, crown length ratio, total number of branches, and mean branch diameter (Table 2). Possibly light levels become critical for branch growth and longevity in the lower crown at stand densities above 25 m^2/ha.

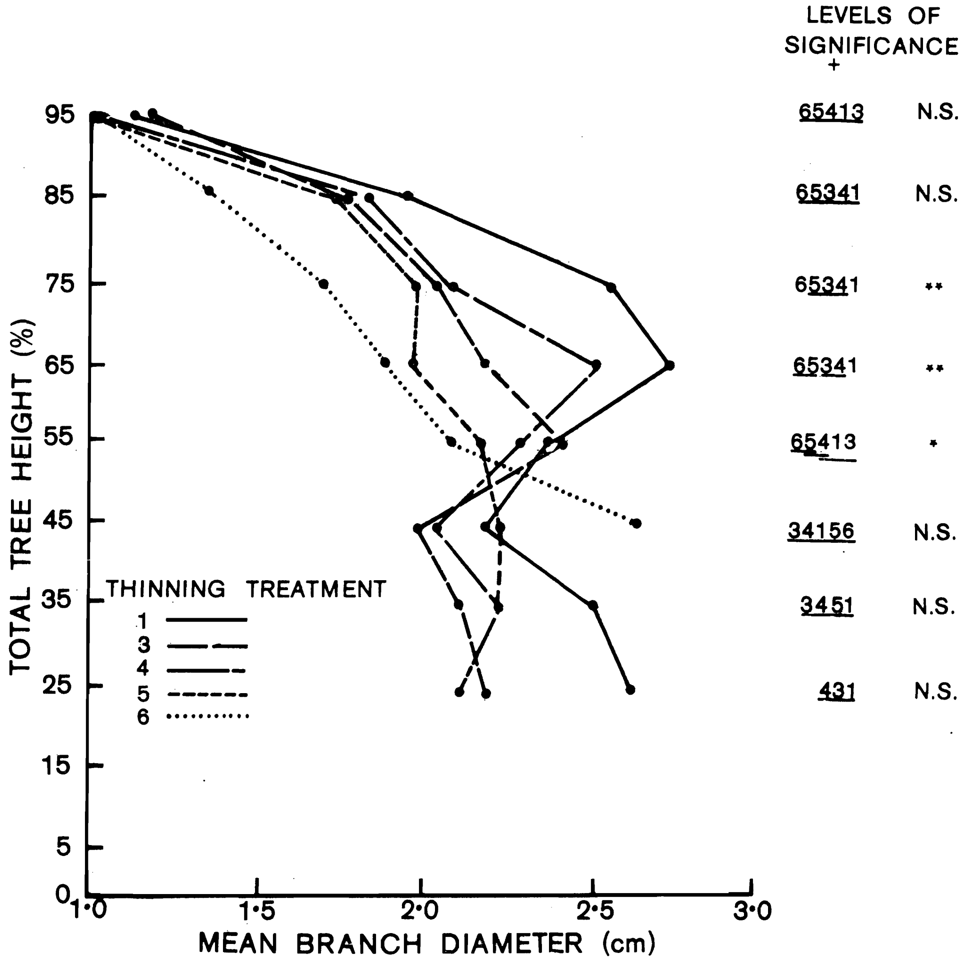

FIG. 1—Variation of branch diameter with height in the crown. Points plotted are means for all whorls within each stratum (10%) of tree height.

+ Underscoring indicates non-significant differences between treatments at p = 0.05.

Beekhuis (1965) found for closed stands of radiata pine in New Zealand that, in the absence of thinning, crown length remains nearly constant, height to the lowest green whorl increasing at approximately the same rate as total height. This implies a decrease in crown length ratio over time. Stiell (1966) observed similar results in *P. resinosa* Ait. If such stands are thinned, however, crown length usually will increase. Beekhuis concluded ". . . to obtain a reliable estimate of crown depth under different thinning regimes, both stand density and stand height have to be taken into consideration."

Crown length ratio (or crown percent) has received considerable attention in the

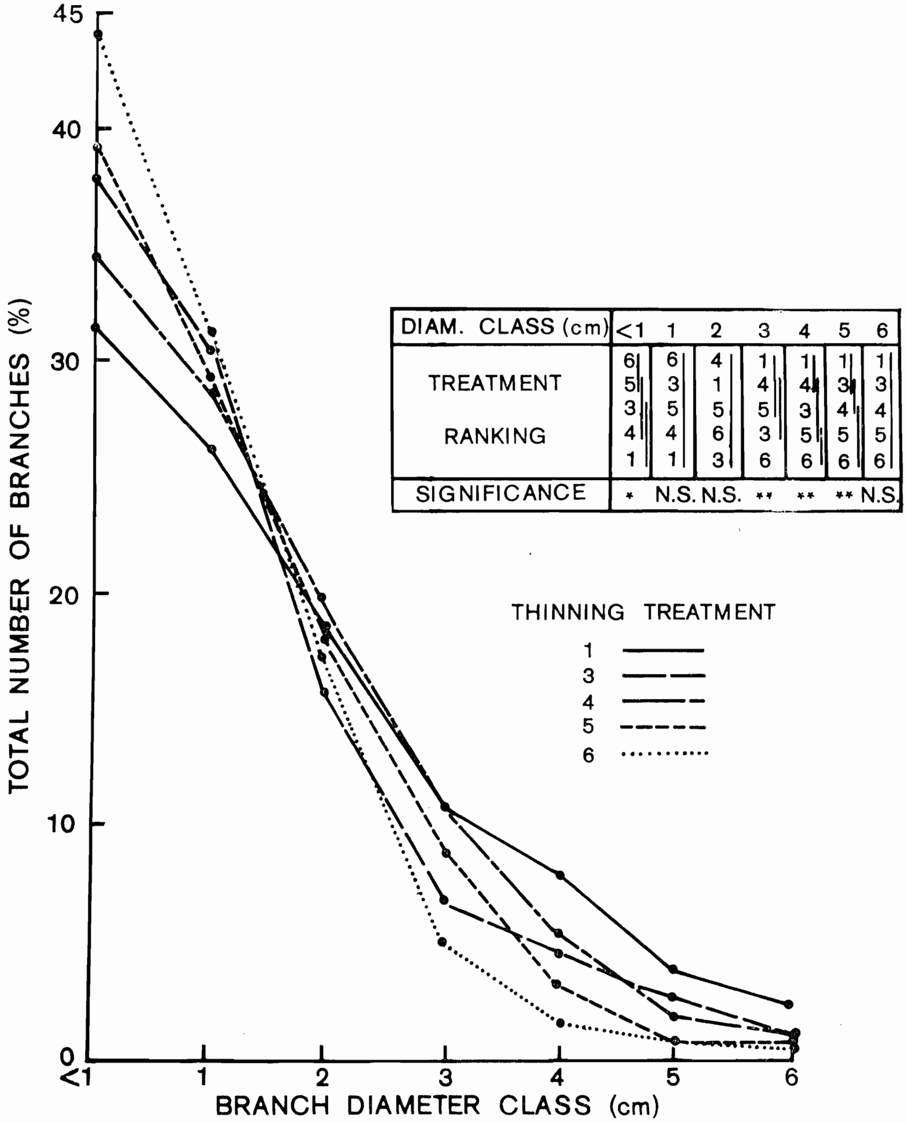

FIG. 2—Distribution of branches by diameter class within the green crown. N.S. = non-significant; * = $p < 0.05$; ** = $p < 0.01$.

literature. Loomis *et al.* (1966) found the ratio varied from 0.55 to 0.35 in *P. echinata* Mill. stands covering a range of stand densities similar to the range of densities in this study. However, the ratio for radiata pine in this study varied from 0.76 in open stands to 0.52 in the most dense stand. Keister *et al.* (1968) reported that crown length ratio in 40-year-old *P. elliottii* Engelm. was unaltered when stands were thinned by four classical methods. Obviously, the crown length ratio varies with species,

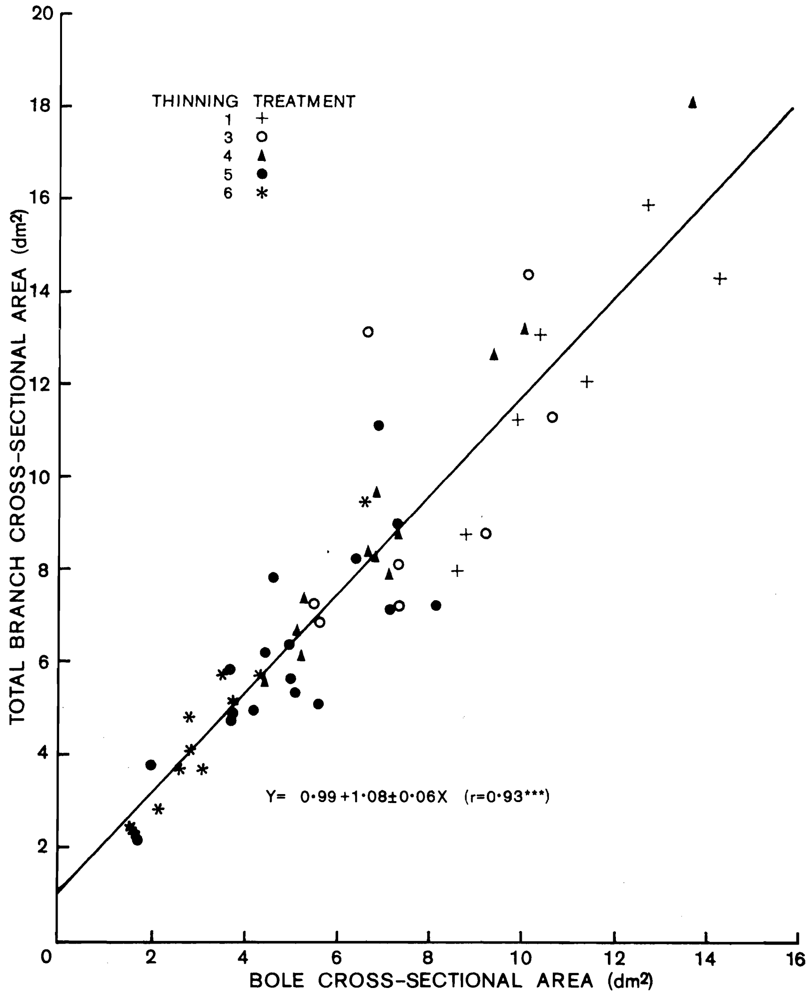

FIG. 3—Relationship between bole cross-sectional area at the base of the green crown and total branch cross-sectional area within the crown.

age and stand density. In stands held at a constant density by repeated light thinnings, the ratio could be expected to decrease with increasing stand height because crown length would tend to remain relatively constant (Beekhuis, 1965; Stiell, 1966).

In this study, the influence of thinning on branch size is confined mainly to the zone at 50-80% of total tree height. In the most open stands, branches in this zone receive full sunlight whereas in the densest stands such branches are shaded. Presumably the branches above 80% of total tree height are free from competition for light irrespective of stand density. In New Zealand, James and Tustin (1970) found that thinning radiata pine affects branch development even at the base of the crown. In this study, the mean diameter of branches at the crown base was not significantly different between treatments but thinning increased green crown depth markedly due to increased branch longevity. However, the vigour of branches in the 20-40% height zone was already low at the time of first thinning in 1962; observations elsewhere suggest branches once suppressed, might live indefinitely after thinning but rarely regain active growth.

The highly significant relationship between cross-sectional area of all branches in the tree and the cross-sectional area of the bole at the base of the green crown, independent of thinning treatment, supports the finding of Jacobs (1938) for radiata pine. Similar results have been observed on other species of markedly different growth habit e.g. *Eucalyptus obliqua* L'Herit. (Curtin, 1970).

The generally accepted lower limits of standing basal area in managed radiata pine plantations in Australia range from 23 to 30 m^2/ha depending on age and site quality (Shepherd, 1970). Trees grown at these densities would have crowns differing noticeably from the crowns of trees growing in unthinned stands. Most significantly, managed stands at age 23 would have green branches along 70-75% of the total tree length (in contrast to approximately 50% in unthinned stands), approximately 25-30% more green whorls and branches, and individual branches of greater size (up to 50% greater diameter in the mid-crown). More intense thinning to basal areas less than 23 m^2/ha, desirable if management intent is to maximise individual tree growth, generally would have little additional effect on these crown characteristics. However, the stand of this study was first thinned when branches in the lower crowns were already suppressed. Branches would live longer and grow larger in stands either thinned at an earlier age to similar basal area levels or maintained throughout their life in a free-growing state.

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REFERENCES

BEEKHUIS, J. 1965: Crown depth of radiata pine in relation to stand density and height. **N.Z. J. For. 10 (1):** 43-61.

CURTIN, R. A. 1970: Dynamics of tree and crown structure in **Eucalyptus obliqua. For. Sci. 16 (3):** 321-8.

FIELDING, J. M. 1960: Branching and flowering characteristics of Monterey pine. **Bull. For. Timb. Bur. Aust. 37.** 59 pp.

FORREST, W. G. and OVINGTON, J. D. 1970: Organic matter changes in an age series of **Pinus radiata** plantations. **J. appl. Ecol. 7 (1):** 177-86.

JACOBS, M. R. 1938: Notes on pruning **Pinus radiata.** Part 1. Observations on features which influence pruning. **Bull. Commonw. For. Bur. Aust. 23.** 47 pp.

JAMES, R. N. and TUSTIN, J. R. 1970: Diameter response of branches after thinning in radiata pine. Paper 20 **in** "Pruning and Thinning Practice". **N.Z. For. Serv., For. Res. Inst., Symposium 12.**

KEISTER, T. D., CROW, A. B. and BURNS, P. Y. 1968: Results of a test of classical thinning methods in a slash pine plantation. **J. For. 66 (5):** 409-11.

LOOMIS, R. M., PHARES, R. E. and CROSBY, J. S. 1966: Estimating foliage and branchwood quantities in shortleaf pine. **For. Sci. 12 (1):** 30-9.

SHEPHERD, K. R. 1967: Influence of low pruning on first thinnings in radiata pine plantations. **Aust. For. 31 (1):** 45-9.

——— 1970: Thinning practice in Australian plantations. **In** "Thinning and Mechanisation". **Proc. Mtg. Int. Union For. Res. Organ., Stockholm. pp** 69-77.

SHEPHERD, K. R. and FORREST, W. G. 1973: Growth of radiata pine following thinning. **Commonw. For. Rev. 52 (2):** 133-42.

SOKAL, R. R. and ROHLF, F. J. 1969: "Biometry: The Principles and Practice of Statistics in Biological Research". W. H. Freeman and Company, San Francisco.

STIELL, W. M. 1966: Red pine crown development in relation to spacing. **Canada, Dep. For., Publ. 1145.** 44 pp.

WOLKSI, J. 1965: Rules for selecting sample trees representative of the pine stands investigated, and determination of the number of such trees. **Prace Institute of Technology Drewna 12 (1):** 87-103. **For. Abstr. 27:** 2714 (1966).