ARTICLES

Analysis of growth and yield from three Kaingaroa thinning experiments

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ABSTRACT

This paper examines net basal area/ha and mean dbhob development in three replicated radiata pine thinning experiments in Kaingaroa Forest. Stockings represented range from 200 to 1300 stems/ha. The analysis here is focussed, however, on lower stockings (200, 300 and 400/ha), primarily because of the interest of forest managers in the reliability of yield forecasts for low stocking regimes. By age 24 years in the oldest of the three trials, it was evident that whereas basal area trends for stockings of 300/ha and above were similar and logically related one to the other, the 200/ha stockings had a noticeably lower growth trajectory path. The same consistent trends were demonstrated in the younger trials. Mean dbhob of the top 200 in stockings of 200, 300 and 400/ha were not as different as might have been expected. Pruning schedules imposed on two of the trials are difficult to analyse adequately, because of inadequate replication. It is important to continue measurement in these experiments for at least another ten years.

It is now over 20 years ago that Fenton and Sutton (1968) proposed a tending regime for *Pinus radiata* in New Zealand, which, at the time, represented a radical departure from the then conventional silviculture. In essence, the regime recommended heavy early thinning to waste, with pruning in three lifts, to shorten rotations to 25-26 years, and to concentrate growth on the pruned butt log so as to produce sawlogs with average dbhob estimated to be around 58 cm. In a later contribution, Sutton (1976) gave estimates of 63.7 m^2/ha of basal area and a mean diameter of 64.5 cm at age 26, achievable in stands thinned to 198 stems/ha when top-height is 10.7 m for a site index of about 29 m.

At the time, the amount of long-term mensurational data available to support these yield estimates was scant. Accordingly, between 1969 and 1973 Messrs J.W. Shirley and D.A. Elliott, then of the New Zealand Forest Service, established four well-replicated thinning experiments in different compartments of Kaingaroa State Forest. These trials are now between 19 and 24 years old with up to 18 annual remeasurements; they provide a rare opportunity to study growth development of various thinning regimes, obtained from extensive and reliable data. What we have done, and now report here, is an analysis of basal area and dbhob development in three of those trials. The comparisons were of considerable interest to us and are likely to be also to forest managers today; emphasis here is placed on presentation of the major results to date, without full details of statistical analyses.

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EXPERIMENTAL DATA

Trial R695

Established 1971, in Compartment 84, altitude 439 m, in a stand of second-crop *Pinus radiata* primarily from regeneration in 1964. Reduced to 2500-3500 stems/ha, when top-height reached 1.5 m. Stocking in the trial area of 6 ha was reduced to 1000-1500 stems/ha in 1971; plots of 0.2 ha were formed, with inner 0.1 ha measurement plots. Four replications of the following residual stockings in stems/ha were represented:

200, 300, 400, 500, 600, 700, and 'unthinned'.

All trees in the measurement plots were pruned to a schedule of:

0 to 2.2 m (1971)
2.2 to 4.2 m (1972)
4.2 to 6.0 m (1973)

The dbhob of all trees and the heights of a sample of 12 to 15 trees per 0.1 ha inner plot were remeasured at least once each year up to age 20, and then at two-yearly intervals to age 24. Non-sampled heights were estimated through the Petterson equation (Schmidt, 1967).

Trial R696

Established late 1971, in Compartment 375, altitude 448 m, in a stand of second-crop *Pinus radiata* cutover in 1966. Thinned to about 2700 stems/ha in 1969, then to the experimental stockings in 1971. The following residual stockings (stems/ha), were imposed with the number of replications given in parenthesis.

200 (4), 400 (8), 600 (8), 800 (4)

All trees in the measurement plots were pruned to one of the following schedules:

- for 200 and 800/ha stockings, 0 to 2.1 m (1971)
- for 400 and 600/ha stockings,

Replications	Lifts
2	unpruned
4	0 to 2.1m (1971)
2	0 to 1.8m (1971)
	1.8 to 4.2m (1973)
	4.2 to 6.0m (1975)

Measurement and other trial details are essentially as for Trial R695.

Trial R699

Established 1973, in Compartment 128, altitude 454 m, in a stand of second-crop *Pinus radiata* cutover in 1969. Thinned to about 2500 stems in 1971, then to the experimental stockings in 1973. The following residual stockings in stems/ha were represented, each replicated four times.

200, 400, 600, 800 and 1000

Pruning in this trial did not begin until 1975; only some of the replicates of 400 and 600/ha were given medium and high pruning.

- for stockings of 200, 800, 1000/ha, 0 to 2.1 m (1975)
- for stockings of 400/ha,

Replications	**Lifts**
2	0 to 2.1 m (1975)
2	0 to 1.8 m (1975)
	1.8 to 4.2 m (1977)
	4.2 to 6.0 m (1979)

- for stockings of 600/ha,

Replications	**Lifts**
1	unpruned
1	0 to 2.1 m (1975)
2	0 to 1.8 m (1975)
	1.8 to 4.2 m (1977)
	4.2 to 6.0 m (1979)

RESULTS

Table 1 provides the initial and latest net basal area/ha, together with site index (mean top height in m at age 20 years) for all the residual stockings. Figures given are averages over all pruning schedules. Basal area development for only the lowest three stocking densities in each trial is shown in Figure 1, to reduce confusion that would otherwise arise from including more stocking levels.

Table 1 : Basal area data and actual site index for R695, R696 and R699

Basal area (m^2/ha) for stockings/ha of	200	300	400	500	600	700	800	>999
R695								
age 7	1.9	2.5	3.4	3.8	5.1	5.8	-	10.7
age 24	37.2	45.4	50.2	52.1	54.7	57.2	-	62.8
site index (m)	29.4	30.6	31.0	30.2	30.6	30.8	-	32.1
R696								
age 6	1.2	-	2.2	-	3.1	-	3.6	-
age 21	32.1	-	45.4	-	51.7	-	54.7	-
site index (m)	28.9	-	29.6	-	30.3	-	29.6	-
R699								
age 4	0.5	-	0.9	-	1.0	-	1.1	1.3
age 19	35.2	-	45.5	-	50.4	-	56.3	56.2
* site index (m)	29.0	-	29.0	-	30.0	-	30.7	30.1

* age 19 heights projected 1 year ahead using KGM3

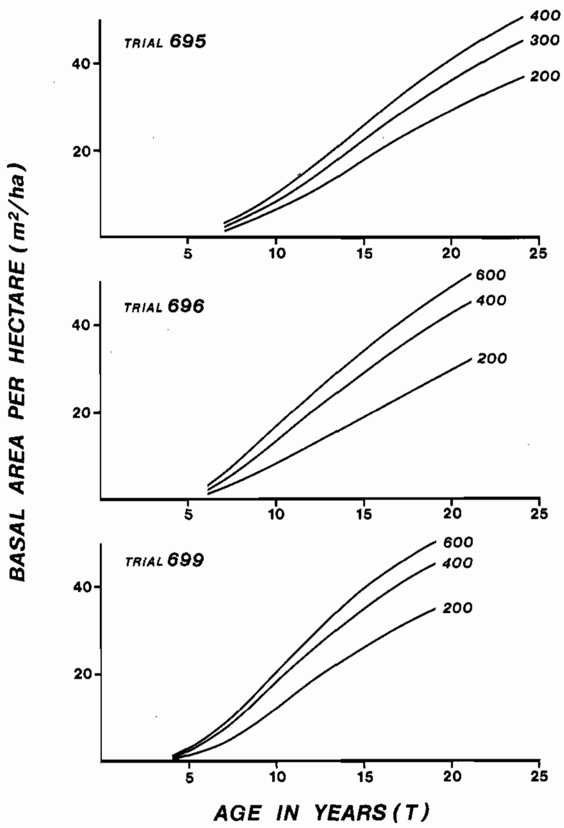

Fig. 1 Stand Basal Area Development with Time.

Figure 1 suggests that, to date, the 200/ha regime has lesser increment development than the others. Accordingly, a yield equation of the form

$$Gnet = \exp(a - \beta y^{T}) \qquad (1)$$

where Gnet = net basal area in m^2/ha at age T years

exp = exponential

= a, ß, y coefficients fitted by non-linear least squares,

was fitted to all the annual net basal area/ha data for each experimental plot in each trial. Model (1) above was chosen from among three candidate equations and preferred because of superior goodness-of-fit. The averages for each coefficient by stocking, treatment and trial are shown in Table 2.

Table 2 : The α, β and γ coefficients averaged by stocking for the Gompertz model predicting net basal area yield.

Trial	Coefficients	200	300	400	500	600	700	800	1000
		Stocking Density (stems/ha)							
R695	α	3.89	4.09	4.13	4.17	4.16	4.21	-	-
	β	8.58	8.18	8.14	7.53	7.68	7.04		
	γ	0.87	0.87	0.86	0.86	0.85	0.85	-	-
R696	α	3.82	-	4.05	-	4.15	-	4.14	-
	β	8.21	-	8.34	-	7.74	-	6.87	-
	γ	0.86	-	0.84	-	0.84	-	0.85	-
R699	α	3.76	-	4.01	-	4.10	-	4.10	4.12
	β	9.08	-	7.52	-	7.68	-	8.50	8.49
	γ	0.79	-	0.82	-	0.83	-	0.82	0.80

In the above equation, the a coefficient represents an upper asymptote or a maximum attainable basal area, whereas the ß and *y* coefficients describe growth (rate) towards the maximum. In general, retarded or low yields over time are represented by lower *a* values, but higher ß and *y* coefficients. Detailed statistical analysis of the coefficients is being presented elsewhere (Whyte and Woollons, 1989). Table 2 clearly shows, however, that there is a marked fall-off in the *a* coefficients for the 200/ha regimes, and higher ß or *y* coefficients, indicative of restricted growth and yield up to age 24 at that stocking.

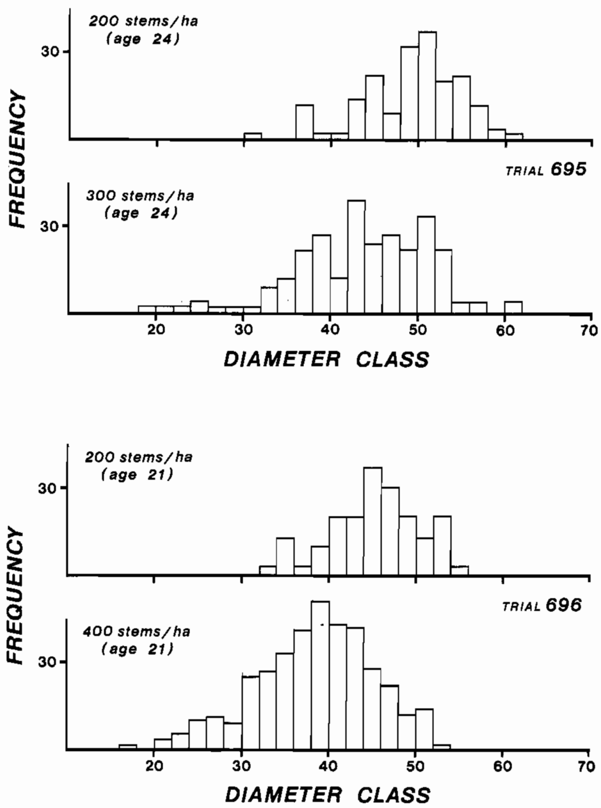

Fig. 2 Latest Dbhob Frequencies/ha in 2 cm Classes.

Figure 2 shows the diameter distributions for the lowest two stockings at the oldest age available in each of trials R695 and R696 (the stem diameters for R699 are not currently available to the authors). Corresponding mean diameter statistics for the largest 100/ha, the largest 200/ha and for all trees are shown in Table 3a for the lower stockings in those two trials at several ages. Table 3b indicates the development of the largest 100/ha over time.

Although there is logically a marked drop in average dbhob for all stems/ha, the average for the largest 200 and 100/ha in the 200 to 400/ha stocking range are not so far apart [maximum difference is 42 mm for the largest 100/ha and 29 mm for the largest 200/ha, to age 24].

Table 4 gives the initial and latest net basal area/ha for 400 and 600/ha, subdivided by pruning schedules and experiment. Apparent loss of basal area through pruning is particularly noticeable in R699, although paucity of replication and differences in initial growing stock unfortunately confound these results and also debar use of covariance analysis.

Table 3: Mean dbhob statistics for low stockings in R695 and R696

(a) Current statistics

Trial	Age	Stocking/ha	Mean dbhob (mm) for: Largest 100/ha	Largest 200/ha	All trees/ha
695	24	200	533	492	492
		300	516	477	439
		400	500	463	402
696	21	200	505	452	452
		400	463	434	384

(b) Development of largest 100/ha (mm) for stockings of

	Age	200/ha	300/ha	400/ha
R695	7	121	118	128
	9	199	192	199
	11	257	245	255
	13	321	305	311
	15	376	358	360
	17	424	406	402
	19	461	441	431
	22	509	492	475
	24	533	516	500
R696	6	101	-	104
	8	184	-	185
	10	249	-	246
	12	316	-	303
	14	370	-	350
	16	415	-	390
	18	458	-	424
	21	505	-	463

DISCUSSION

Economic comparisons of different stockings depend partly on the reliability of crop mensurational data. Results given here confirm that earlier predictions of likely crop yields and piece sizes obtainable from residual stockings of 200/ha with the forecasting tools then available were too optimistic. The evidence of lower basal area yields from these three well replicated experiments is quite convincing, and there is little possibility that yields or mean dbhob forecasted by, for example, Sutton (1976) will be achieved in stockings of 200 stems/ha by age 26, certainly not in Central North Island plantations on non-farm sites.

The use of a yield equation to represent plot basal area development provides an efficient method of summarising the data, and allows a discerning analysis of growth to date for each stocking treatment. It is important, however, to interpret the coefficients derived strictly within the age span of the experiments; for example, they ought not to be used to provide estimates of likely future yield for each stocking, as there will be later, as yet unrepresented interactions of mortality and available growing space.

Table 4 : Mean basal area statistics for pruning schedules in R696 and R699

Basal area (m^2/ha) for stocking schedule combinations of

	400/ha unpruned	400/ha 0/2.1	400/ha 0/6	600/ha unpruned	600/ha 0/2.1	600/ha 0/6
R696						
age 6	2.1	2.2	2.3	3.0	3.1	3.1
age 21	46.9	44.6	46.1	54.9	51.7	50.1
R699						
age 4	-	1.1	0.7	1.5	0.7	1.0
age 19	-	48.7	40.2	57.1	50.6	47.0

There is, however, some evidence that the degree of retardation evident in these experiments for 200/ha may in part be a function of thinning practice actually carried out in these trials. While great care was taken to choose the residual trees, there is always the possibility that negative selection had been practised. This may have been caused by over-adherence to spacing and stem form criteria as opposed to tree vigour. D. Elliott *(pers. comm.)* comments that at trial establishment, each plot was subdivided into quadrants, and that the selection criteria demanded an exactly equal number of residual stems in each subplot. Thus, there is some chance that yields obtained to date in these experiments may be a little pessimistic. Conversely, we believe it would be foolish to dismiss these results on the grounds of too careful and constrained a choice of crop trees, which notion, in any event, assumes that operational thinning practice is always to thin strictly from below. Indeed, it is most unlikely that routine thinning throughout New Zealand forests would circumvent this problem; rather it may exacerbate the tendency to negative selection because of lesser time taken to choose which crop trees to retain.

A particularly surprising feature of these results is the small gains to date in mean dbhob for the 200/ha stockings compared with the largest 200/ha in 300 and 400/ha stockings. Certainly, the maximum diameter is logically greatest for the 200/ha stockings, in which there is also some evidence of superior diameter increment. Conversely, each of these has a lower tail to its diameter distribution, suggesting only a proportion of the 200/ha crop will have an appreciable gain in dbh. Perhaps this wide a range of diameters may be partially obviated with the availability of increasingly improved genetic stock, but the means to test this suggestion will not be available for quite a few years yet.

The evidence for loss of basal area growth through pruning is not conclusive. Trial R696 appears to be little affected, yet R699 suggests appreciable retardation. Attention has already been drawn to the inadequate replication of pruning schedules available, which is further compromised by mortality and differing initial basal area within stockings. But the evidence does suggest that further examination of such an impact is warranted.

The experiments reported here have provided considerable information of interest to the forestry sector; every endeavour should be made to continue remeasuring them for at least another 10 years.

CONCLUSIONS

This analysis of about 20 years of measurement from three replicated Kaingaroa thinning trials indicates that:

(1) stockings of 200/ha will most likely produce yields at rotation age lower than earlier predictions would have suggested;

(2) up to age 24, basal area growth for residual stockings of 200/ha is less than for 300/ha or higher stockings;

(3) gains to date in average diameter for all trees in the 200/ha stockings differ by no more than 29 mm over the same top 200 elements for 300 and 400 stems/ha stockings, while the corresponding difference for the top 100 is 42 mm;

(4) managers should monitor the appropriateness of thinning prescriptions to check that tree vigour is not being unduly constrained by selection of crop trees in terms of regularity of spacing, stem form, light branching and other characteristics associated with lower vigour;

(5) different pruning schedules imposed within R696 and R699 are difficult to analyse, because of inadequate replication, chance mortality, and differences in initial basal area, but there is some suggestion that severe pruning has also reduced growth.

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