GROWTH OF RADIATA PINE UNDER THE DIRECT SAWLOG REGIME

B. R. MANLEY and R. L. KNOWLES*

ABSTRACT

In order to analyse the growth of radiata pine (Pinus radiata *D. Don*) *managed under the direct sawlog regime, plots were sought which had been thinned to a final stocking of about 200 stems/ha near the time of high pruning. Data were available for a total of 43 plots at 23 locations throughout New Zealand, including 22 plots at 10 different trials in the Rotorua region.*

Growth trends differed between regions, indicating the need for growth models (when based on top height) to be prepared regionally.

Estimates based on the extrapolation of straight-line regressions for each Rotorua-region trial predict a basal area in the range 39-46 m^2/ha at top height 36 m. Extrapolation of an overall linear regression for the nine, planted, butt-log-pruned, Rotorua plots resulted in an estimate of 44 m^2/ha basal area at top height 36 m. A similar estimate based on the six regenerated plots gave about 41 m^2/ha. However, estimates for planted, butt-log-pruned plots at Mangatu, Gwavas, and Santoft forests tended to be between 56 and 64 m^2/ha at top height 36 m. Estimates for Mohaka, Te Wera, Golden Downs, and Otago Coast forests (based on limited data) lie within or beneath the estimated range for the Rotorua region.

Results indicate that the Beekhuis yield-prediction method is inappropriate for stands in the Rotorua region which have been thinned early and heavily; for these the Kaingaroa Growth Model gives a better estimate. However, data from Mangatu, Gwavas, Santoft, and Ngaumu forests suggest that the Beekhuis method may be suitable for the direct sawlog regime on at least these forests.

INTRODUCTION

Problems with production thinning of radiata pine in New Zealand have led to the development of "direct" sawlog regimes. The first was proposed by Fenton and Sutton (1968) who argued that

* Forest Research Institute, Private Bag, Rotorua.

yield-oriented regimes stipulating one or more production thinnings to avoid mortality (as described by Penistan, 1960) were proving impracticable and, because of restricting growth on pruned butt logs, may not give the best financial return.

The 1968 proposal was for an initial stocking of 1538 stems/ha, with the first thinning (to waste) to 371 stems/ha at top height† 10.7 m, and a final thinning to waste to 198 stems/ha at top height 16.8 m. Pruning of the butt log was to be done in three lifts to a height of 6.1 m.

Projections of final tree size were described by Fenton and Sutton (1968) as being "somewhat subjective". They considered yield projection from Beekhuis (1966) to be optimistic when applied to stands which received the proposed early, heavy thinning. This seems appropriate as the regime was outside the limits set for the application of the Beekhuis method. Plots at Woodhill, Ngaumu, and Golden Downs forests indicated that actual increment was generally less than that predicted using the Beekhuis growth model. A modified form of the Beekhuis method was therefore used for a profitability analysis of the direct regime (Fenton *et al.,* 1968) — three-quarters of the predicted basal area up to height 22.9 m, with the full prediction applicable after this height. A site index of 29 m was assumed, with a basal area of 8.5 m^2/ha on 371 stems/ha at 10.7 m top height, and 12.6 m^2/ha on 198 stems/ha at 16.8 m top height. Clearfelling was to be at top height 36.9 m at 26 years, when the predicted basal area was 54.5 m^2/ha and the mean tree diameter 59.2 cm.

The regime was slightly modified by Fenton *et al.* in 1972. The changes were that thinning to 620-740 stems/ha accompanied low pruning, and that thinning to the final-crop stocking was to be by chainsaw (instead of poison) on completion of high pruning at top height 10.7 m. More optimistic growth rates were projected. On a site index of 29 m, a basal area of 4.7 m^2/ha on 198 stems/ha was estimated at top height 10.7 m. Between 10.7 and 13.7 m top height only 3.9 m^2/ha (approximately one-half of that predicted by Beekhuis) basal area increment was estimated. After 13.7 m the full Beekhuis projection was used predicting a basal area of 58.9 m^2/ha on 197 stems/ha at top height 34.5 m. However, because of expected reduction in height growth caused by pruning and thinning, it was predicted that stands grown under

†Throughout this paper mean top height (MTH) and predominant mean height (PMH) are assumed to be equivalent and the term top height is used for both.

the direct regime would be 2 years older than indicated from height-age tables. An elaboration of this method has been given by James (Fenton, 1972).

Although the results of the profitability analyses strongly favoured the direct regime over the production thinning regime (Fenton *et al.*, 1972) there is still considerable controversy about the direct sawlog regime — particularly in respect of the final-crop stocking. One reason for this controversy has been the sketchy nature of the yield projections for heavily thinned stands.

A full examination of this issue should not only include a more accurate prediction of the final-crop basal area, but it should also take into account all the other factors which may be affected — for example, mortality and timber grades. This paper relates mainly to the growth of stands which have been thinned to a final crop of about 200 stems/ha at high pruning. Where plots thinned to different stockings were available on the same site, the opportunity was also taken of examining the relativity (on the basis of growth only) of regimes involving different final-crop stockings.

METHOD AND DATA SOURCE

Since 1968, plots have been established in forests throughout New Zealand to provide information on the growth of stands receiving early, heavy thinning. Some of these plots now have top heights exceeding 30 m. Many are not adequately replicated to permit statistically valid analysis on each site, yet in total these plots represent a considerable pool of data.

A search was made to locate such trials in radiata pine stands that had been thinned to about 200 stems/ha at the time of high pruning to 6 m, and which had been remeasured at least 5 years after thinning. For the Rotorua region where more data were available, the criterion used was to analyse only plots in the 178-227 stems/ha stocking range which had attained a top height of 24 m.

If there were also plots thinned to stockings of less than 425 stems/ha at the time of high pruning these were analysed as well.

Table 1 lists the 25 trials analysed and gives the number of plots in various stocking classes at each location. The 10 trials in the Rotorua region included five trials in Kaingaroa State Forest, three in Ellis and Burnand's Waratah and Mill plantations near Putaruru, and one trial in each of Whakarewarewa State Forest and Tasman Pulp and Paper Co. Ltd's Tarawera Forest.

These 10 Rotorua trials contain 22 of the 43 plots in the 178-227 stems/ha stocking class. All plots in this category were pruned to about 6 m in one to three lifts, except for the plots in Mohaka Cpt 25 and Gwavas Cpt 29 which were only low pruned. In addition, seven of these plots were second-log pruned to 11 m. These

TABLE 1: DISTRIBUTION OF PLOTS BY LOCATION AND STOCKING

Trial Location	*Stocking (stems/ha)*				
	111-132	*178-227*	*237-287*	*290-330*	*345-425*
Whakarewarewa Forest:					
Cpt 21		2		1	1
Tarawera Forest		2			9
Ellis and Burnand:					
Waratah Cpt 7		4			
Waratah Cpt 5	2	3			
Mill Stand		2			
Kaingaroa Forest:					
R911 — Cpt 1304		3			
R680 — Cpt 1119		1			2
R681 — Cpt 48		2		1	2
R488 — Cpt 158		1			1
R694 — Cpt 901		2	1	2	1
Mangatu Forest:					
R1103 — Cpt 1		1			
R1106 — Cpt 27		3			3
R1118 — Cpt 36		1			
Mohaka Forest:					
Cpt 25		1			
Cpt 54		1			
Gwavas Forest:					
Cpt 29		1			
WN 216 — Cpt 30		3			
Cpt 65			1		
Ngaumu Forest:					
WN 227 — Cpt 110			1	1	
Te Wera Forest:					
WN 197 — Cpt 32		2	1		1
Santoft Forest:					
Cpt 4		1			1
Golden Downs Forest:					
NN278 — Cpt 113	2	2	4		4
NN300 — Cpt 159		3			
Otago Coast Forest:					
SD118 — Cpt 155		1			
Berwick Forest:					
SD327		1			

FIG. 1: *Plot 1, Cpt 21, Whakarewarewa Forest is typical of the plots used in the analysis. Thinned to 198 stems/ha after high pruning at 11 m height, it is now 26 m in height 18 years after planting.*

were the four plots at Waratah Cpt 7, the two Mill Stand plots, and one of the Whakarewarewa plots. With the exception of the latter, the plots which were second-log pruned have been periodically topdressed with potassic superphosphate over the measurement period, to encourage understorey pasture for grazing by sheep and cattle.

The plots have had varied thinning histories. Four Kaingaroa trials (R680, R681, R488, and R694) were naturally regenerated and these plots had either one or two intermediate slasher thinnings to reduce their very high initial stockings. The remaining trials were planted at various nominal stockings and were given only one thinning. The timing of the thinning to final-crop stocking varied between top heights 9.0 and 16.8 m. Plot size ranged between 0.0405 and 0.405 ha. Estimated site index varied between 24 and 35 m (Burkhart and Tennent, 1977).

For each of the 85 plots analysed, a time series of measurements of stocking, basal area, and top height was obtained from records up to and including the 1978 remeasurement. All data were screened and any apparent anomalies were checked with the original field sheets.

RESULTS

Relationship of Basal Area to Height

To enable analysis of the growth of the direct sawlog regime, data from all plots thinned to between 178 and 227 stems/ha at the time of high pruning were considered first. Figure 2 graphs the development of net stand basal area with respect to top height for the 22 plots in the Rotorua region. The plots for this region show growth trends that are reasonably parallel. Major exceptions are the four Waratah Cpt 7 plots and one Whakarewarewa plot, growth trends of which tend to cross those of the other plots before travelling parallel to them. As these plots were all second-log pruned during this early phase it seems reasonable to assume that this could explain their apparent lower rate of early basal area increment.

The relationship of basal area to top height for most plots appears to be reasonably linear considering the likely measurement errors associated with height. The most significant deviations from linearity occur in the first measurement period after high pruning and thinning. An analysis of seven Rotorua plots indicated that the average ratio of basal area increment (m^2/ha) to top height increment (m) was 0.76 for this first year.

The growth trends predicted by Fenton *et al.* (1968) and by Fenton (1972) using modifications of Beekhuis (1966) are illustrated in Fig. 2. Clearly, the predicted growth rates are steeper than the actual growth of the Rotorua plots. However, the Fenton *et al.* (1968) estimate is almost parallel to the plot trends while 75% of the increment predicted by Beekhuis (1966) is used. Thereafter the trend is too steep.

The trend predicted by the Kaingaroa Growth Model (D. A. Elliott and C. J. Goulding, pers. comm.) using the same starting value as that of Fenton (1972) is also shown. Within the range depicted, the predicted growth trend is virtually linear and lies within the range of the Rotorua plot trends. Although the model does not appear to allow adequately for the initial retardation of growth after high pruning and thinning, it should be noted that the plots used in this analysis were generally first thinned after high pruning, whereas an earlier thinning at 4.9 m height was assumed in the Kaingaroa model.

Figure 3 illustrates the basal area development of the plots in Wellington Conservancy and also at Mangatu Forest. The one Santoft Forest plot, four Gwavas Forest plots and four of the five

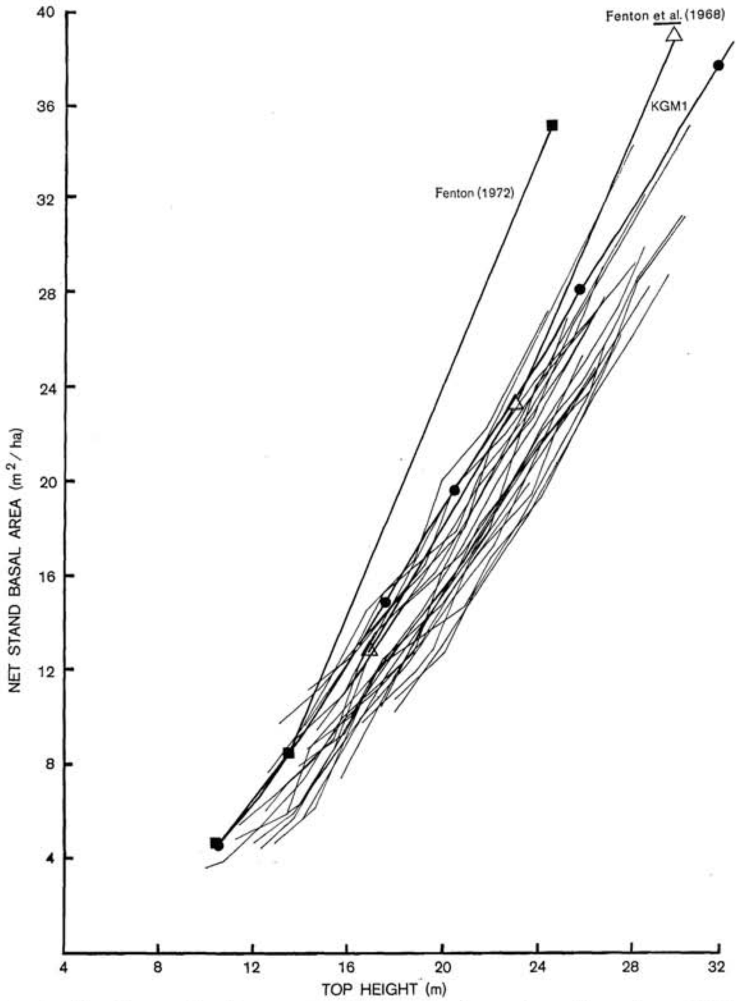

FIG. 2: *Basal area development of Rotorua-region plots thinned to 180-220 stems/ha at time of high pruning.*

Mangatu Forest plots all show a fairly consistent trend and are clustered about the growth trend predicted in Fenton (1972). The fifth Mangatu plot has a lower slope. It is in a more sheltered site than the other Mangatu Forest plots (J. L. Johnston, pers. comm.), and its differing growth trend possibly relates to its higher site index of 35 m (Burkhart and Tennent, 1977).

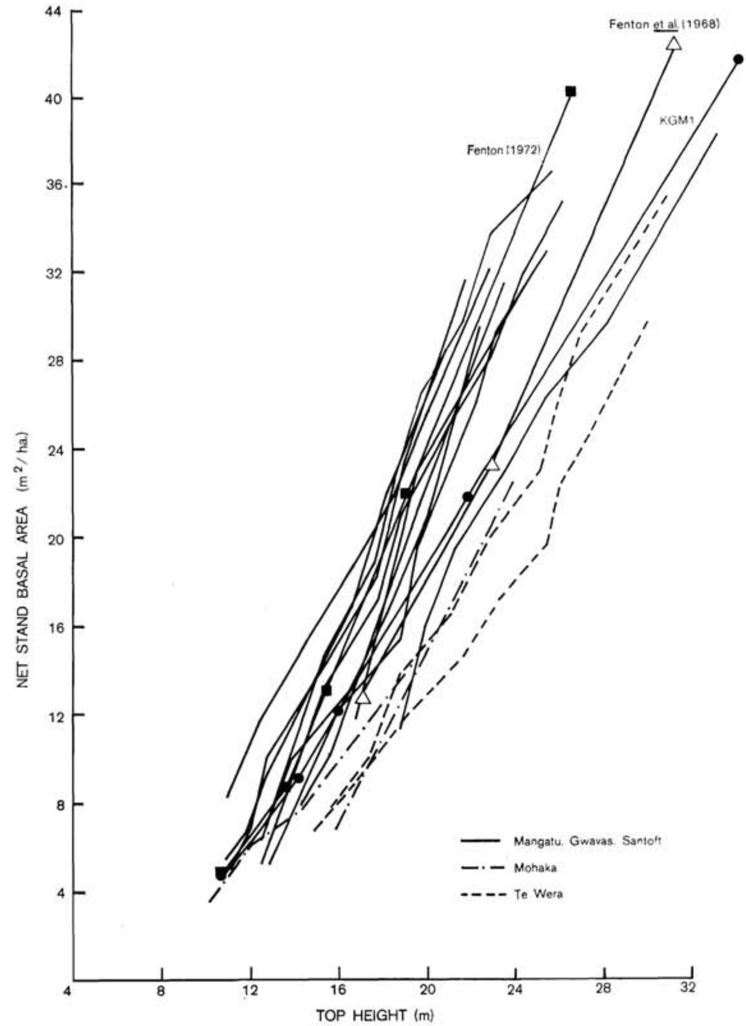

FIG. 3: *Basal area development of Mangatu Forest and Wellington Conservancy plots thinned to 178-227 stems/ha at time of high pruning.*

The two Mohaka and two Te Wera plots have a lower basal area for any given height than most of the Mangatu and Gwavas plots. Their growth trends are similar to those for the Rotorua region.

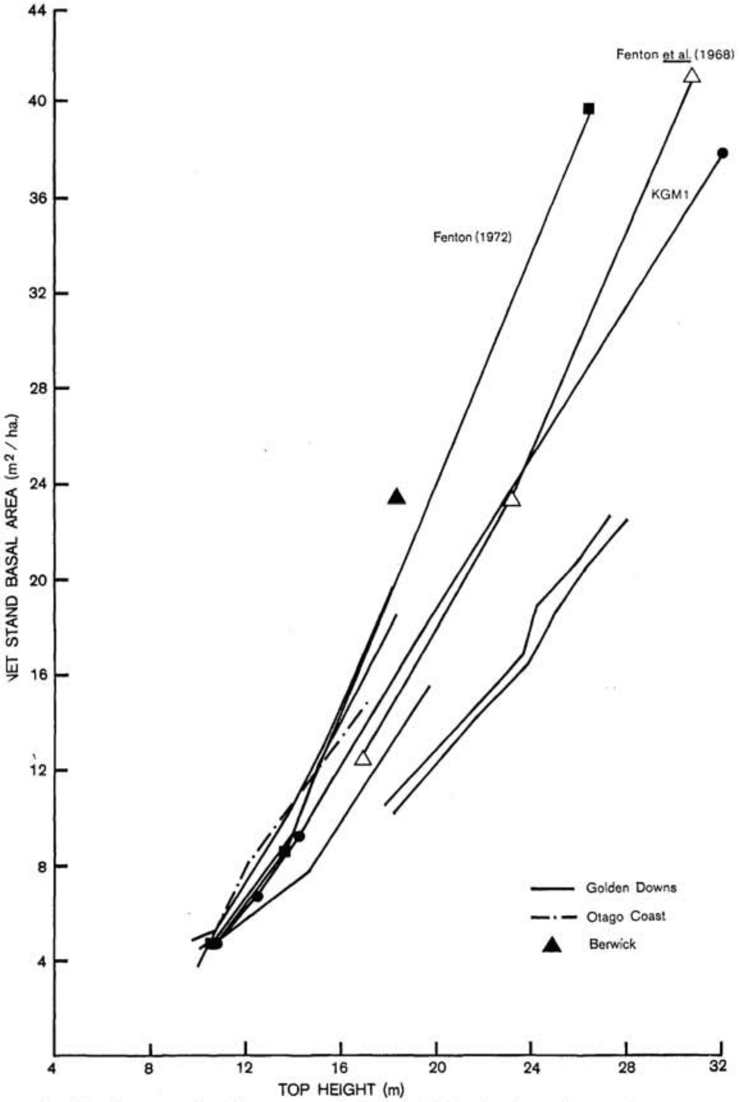

FIG. 4: *Basal area development of South Island plots thinned to 178-227 stems/ha at time of high pruning.*

TABLE 2: LINEAR REGRESSIONS OF BASAL AREA ON TOP HEIGHT FOR PLOTS THINNED TO 178-227 STEMS/HA

Plot	*Pruning Status**	*Site Index (m)* †	*n*	b_0	b_1	r^2	*S.E.$\bar{Y}$ (m^2/ha)*
Whakarewarewa 1	B	28	8	−13.35	1.642	0.995	0.18
2	S	26	8	− 9.63	1.227	0.992	0.16
Tarawera T6	B	34	5	−19.44	1.766	0.989	0.48
T9	B	34	6	−12.27	1.397	0.995	0.23
Waratah Cpt 7 9	S	31	8	−10.87	1.287	0.974	0.40
10	S	30	8	− 9.95	1.414	0.985	0.30
11	S	30	8	−11.44	1.441	0.994	0.19
12	S	30	8	−11.25	1.332	0.986	0.26
Waratah Cpt 5 13	B	30	8	−10.85	1.437	0.992	0.24
16	B	29	8	− 9.75	1.416	0.987	0.28
17	B	30	8	− 9.50	1.298	0.991	0.21
Mill 18	S	32	6	−16.92	1.573	0.996	0.21
19	S	34	7	−21.92	1.755	0.993	0.27
R911 20	B	35	8	−17.36	1.717	0.997	0.21
35	B	33	7	−18.63	1.869	0.994	0.29
60	B	33	10	−15.12	1.613	0.984	0.40
R680 A	B	30	7	−18.60	1.728	0.996	0.18
R681 A	B	31	7	−15.89	1.540	0.985	0.33
B	B	31	7	−14.31	1.487	0.997	0.14
R488 3	B	32	9	−17.83	1.635	0.998	0.12
R694 25	B	30	7	−19.41	1.624	0.999	0.11
26	B	29	8	−19.23	1.709	0.999	0.10
Mangatu R1103	B	35	7	−19.17	1.746	0.997	0.57
R1106 2	B	28	6	−21.26	2.353	0.996	0.24
8	B	29	6	−21.14	2.340	0.976	0.64
14	B	30	6	−21.33	2.171	0.964	0.71
Mangatu R1118	B	28	6	−12.73	1.918	0.992	0.31
Mohaka 25/1	—	30	3	−23.56	1.918	0.999	0.15
Mohaka 54/1	B	31	4	− 7.80	1.135	0.991	0.26
Gwavas 29/3	—	28	4	−29.49	2.579	0.998	0.31
Gwavas WN216 F2	B	29	8	−20.68	2.149	0.995	0.27
F3	B	29	8	−21.94	2.356	0.979	0.56
F4	B	29	8	−24.40	2.253	0.984	0.45
Te Wera WN 197 1	B	31	9	−16.19	1.474	0.982	0.36
3	B	32	9	−21.56	1.839	0.992	0.29
Santoft 4/3	B	24	3	−24.32	2.299	0.999	0.06
Golden Downs							
NN278 9	B	27	6	−12.85	1.290	0.986	0.24
10	B	28	6	−13.23	1.200	0.994	0.16
Golden Downs							
NN300 1	B	30	4	−15.36	1.893	0.989	0.39
4	B	30	4	−14.71	1.786	0.987	0.40
8	B	32	4	− 8.40	1.171	0.957	0.58
Otago Coast SD 188/10	B	26	3	−10.64	1.509	0.992	0.41

*B = Butt log pruned, S = Butt and second log pruned
†From Burkhart and Tennent (1977)

Figure 4 shows the basal area development of the plots in Nelson and Southland. The two plots of trial NN278 at Golden Downs have a very low level and slope. However, the trend of two of the three plots at the other Golden Downs trial appears to follow the prediction in Fenton (1972). There was some mortality in the third plot at NN300 and this may explain its lower growth rate.

The plot at Otago Coast has developed to the stage where it gives only a hint of likely future growth pattern. The single data point of the Berwick Forest plot indicates a high ratio of basal area increment to top height increment.

The growth trend predicted by the Kaingaroa Growth Model is also shown in Figs. 3 and 4 for comparative purposes.

Regression Analysis of Basal Area to Height

A straight-line regression was fitted to the data from each plot, excluding the first year since thinning. Table 2 lists the regression coefficients, the coefficient of determination (r^2), and the standard error of the estimated mean (S.E.$\bar{Y}$), for each plot thinned to about 200 stems/ha. It can be seen that the r^2 values are high (all above 95%) and the standard errors are relatively small. The visual impression from Figs. 2, 3, and 4 also implies that a straight line is a good approximation to the relationship of stand basal area to top height.

There was no significant correlation between the regression slope coefficient and site index. This relationship was tested for the 43 plots of about 200 stems/ha (r^2 = 0.037), all 22 Rotorua plots (r^2 = 0.148), and the 15 Rotorua plots that had not been second-log pruned (r^2 = 0.079).

As is evident from Figs. 2 to 4 there are different relationships between stand basal area and top height in different regions of New Zealand. The slope of the Rotorua plots varies between 1.23 and 1.87. Although Mangatu plot R1103 had a slope of only 1.75 the slopes of the other four Mangatu plots were in the range 1.92 to 2.35. Similarly, the four Gwavas plots with slopes ranging from 2.15 to 2.58 and the Santoft plot with a slope of 2.30 were outside the range of the Rotorua plots.

One Mohaka plot exceeded and the other was less than the Rotorua range of slopes. The two Te Wera plots and the Otago Coast plot fell within the range. The pattern for Golden Downs is somewhat confused; two plots have slopes greater and three plots have slopes less than the range of slopes of the Rotorua region plots.

The modified Beekhuis prediction method used by Fenton *et al.* (1968) assumed a slope of 1.73 between heights of 16.8 and 22.9 m, with a subsequent slope of 2.24.

The prediction method in Fenton (1972) assumed a slope of 1.30 for the first 3 m of height growth after thinning. Thereafter a slope of 2.44 is assumed.

The Kaingaroa Growth Model allows for a reduction in basal area increment for the first 3 years after thinning. When the same starting point as in Fenton (1972) is used, it predicts a slope of about 1.2 for the first year, rising rapidly to a constant slope of about 1.6 in the range 16–32 m height.

Extrapolation of Basal Area for the Rotorua Region

Data from the 22 Rotorua plots were separated into three groups to enable analysis of the relationship of basal area and top height. The groups were:

— planted, butt log pruned;
— planted, butt and second log pruned;
— regenerated, butt log pruned.

All measurements at top height less than 18 m were eliminated. This was done because several plots were not measured until this stage. Additionally, it removed measurements taken during the period of second log pruning.

Regression analysis was made using separate intercepts for each plot. The coefficient for slope was then calculated for each group, together with the confidence interval at the 95% level. The intercept for each group was taken as the mean of the intercepts from all plots in the group.

Table 3 contains the regression coefficients for the three groups using data from 18 m top height.

TABLE 3: LINEAR REGRESSIONS FOR THE ROTORUA REGION (based on measurements with top height greater than or equal to 18.0 m)

Stand Treatment	*n*	b_0	b_1	*95% Confidence Interval of* b_1
Planted, butt log pruned	42	–15.92a	1.665a	±0.110
Planted, butt and second log pruned	35	–18.79b	1.676a	±0.062
Regenerated, butt log pruned	37	–17.90b	1.633a	±0.045

Coefficients with the same letter are not significantly different at the 5% level. Differences in intercept were tested as the differences between mean intercepts for each group assuming constant slope.

The straight-line regressions for the three groups in the Rotorua region presented in Table 3 are based on data with a maximum top height of 30.5 m. Because estimates of basal area beyond this height are of considerable interest, extrapolation of the straight-line relationship derived from the nine plots in the planted, butt-log-pruned, treatment group was used to estimate net standing basal area at future top heights.

TABLE 4: EXTRAPOLATION OF BASAL AREA FOR PLANTED, BUTT-LOG-PRUNED STANDS IN THE ROTORUA REGION

Top Height (*m*)	*Predicted Basal Area* (*m^2/ha*)	*Lower Limit** (*m^2/ha*)	*Upper Limit** (*m^2/ha*)	*Mean Diameter†* (*cm*)
35.0	42.4	38.5	46.2	52.4
36.0	44.0	40.1	48.0	53.5
37.0	45.7	41.6	49.8	54.5

*Limits are 95% confidence limits of the regression
†Assumes final stocking of 196 stems/ha.

It must be remembered when considering these estimates that they are based on a straight-line regression and essentially represent an averaging of the long-term growth trends of these specific Rotorua plots.

The extrapolation assumes that the relationship of basal area to top height will remain linear. Eliminating data at top heights of less than 20, 22, 24, and 26 m gave almost identical slopes to those calculated for the 18 m cut-off point, indicating such an assumption reasonable within the range of the extrapolations made.

Mortality

To date there has been very little mortality caused by competition. Only two Rotorua plots have exhibited any mortality which could be considered competition-induced, and another two have lost stems through windthrow. The average stocking of the 22 Rotorua plots after thinning was 198.2 stems/ha. Competition-induced mortality and windthrow have reduced average plot stocking to 196.6 stems/ha at the time of last measurement (at top heights between 23.7 and 30.5 m). Mean tree diameter in Table 4 was therefore calculated assuming a final stocking of 196 stems/ha.

Slightly more mortality has occurred in plots outside the Rotorua region. Eight of the 21 non-Rotorua plots have had a stocking reduction — three plots have had windthrow only, four plots have had natural mortality, and one plot has had both.

In one Gwavas Forest plot (WN216-F1) windthrow immediately after thinning to 198 stems/ha reduced the stocking to 165 stems/ha and so this plot was excluded from the analysis.

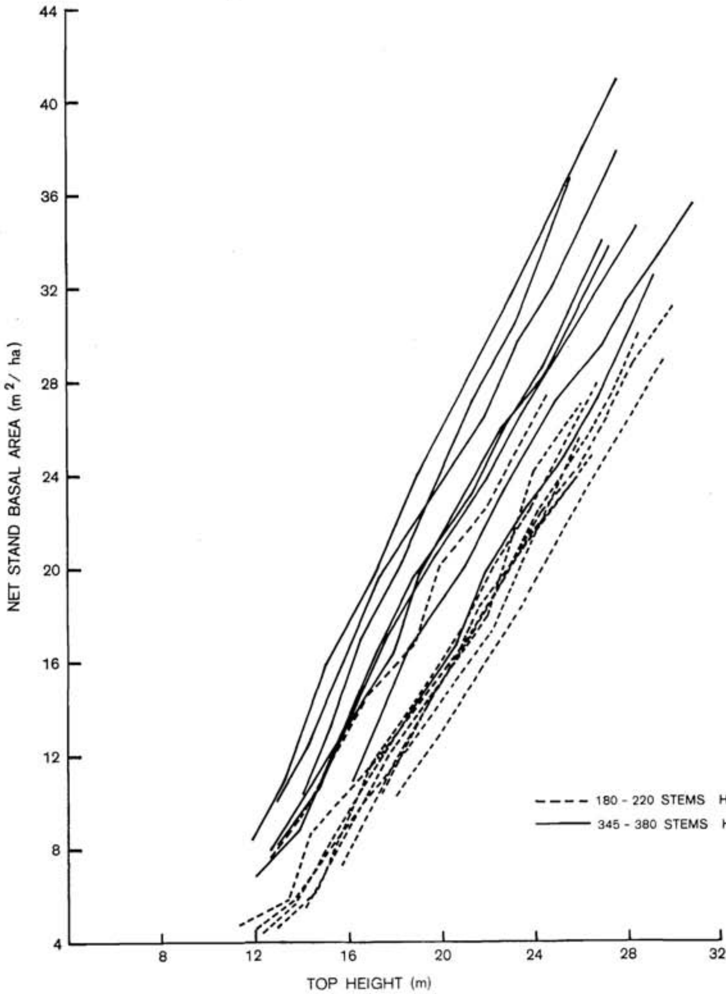

FIG. 5: *Basal area development of plots thinned to 180-220 and 345-380 stems/ha at six sites in the Rotorua region.*

For plots in the 178-227 stems/ha range, the mortality that has occurred though competition has been relatively uniform over the period since the final thinning and has been confined to the odd small tree. Indeed, there is no evidence of accelerated mortality during later measurement periods to indicate that severe competition is taking place. There appears little likelihood of significant competition-induced mortality within the range of the extrapolations up to top height 37 m.

Variation in Tree Diameters

The diameters from 16 planted plots from the most recent measurement (stand age about 17 years) were analysed for distribution about the plot means. The distributions appeared normal, with tests for skewness and kurtosis being non-significant at the 95% level. The standard deviation was 4.82 cm. A similar test on the same plots taken 6 years previously showed the standard deviation as a percentage of the plot mean diameter (*i.e.*, the coefficient of variation) had remained fairly constant at 10–11% of the plot mean diameter.

Comparison with Regimes with Higher Final-crop Stockings

Graphs of basal area on top height for the remainder of plots thinned to stockings less than 425 stems/ha also revealed linear trends. As in the preceding analysis, straight-line regressions were calculated for each plot using all data except those from the first year after thinning. Generally there was not so marked a depression of basal area increment with respect to top height increment for this first year for plots with higher stockings than 198 stems/ha.

At 10 different sites final-crop stockings of 178-227 stems/ha and 345-425 stems/ha were compared. In all trials except at Santoft there is a greater basal area for a given top height with 345-425 stems/ha than with 178-227 stems/ha. In 4 of the 10 trials the relationship of basal area to top height for 345-425 stems/ha has a significantly greater slope* than for 178-227 stems/ha. In five trials the relationship is at a higher level† for 345-425 stems/ha than for 178-227 stems/ha. At Santoft there was no significant difference.

---

*All testing for statistical significance was done at the 5% level.

†To test for level, predicted values of basal area were compared at the mean of the mean values of top height for each regression.

At six Rotorua-region trials, final-crop stockings of 180-220 stems/ha and 345-380 stems/ha can be compared. Figure 5 graphs the growth trends of nine 180-220 stems/ha and eight 345-380 stems/ha plots at these six sites: Whakarewarewa, Tarawera, R680, R681, R488, and R694. The growth trends of the nine 379 stems/ha plots at Tarawera were averaged to produce one line. It can be noted that some overlap exists between the two stocking classes. The pattern of the 345-380 stems/ha plots is more diffuse than that of the 180-220 stems/ha plots.

Extrapolation of Basal Area for Each Trial

Straight-line regressions were extrapolated to calculate an estimate of net basal area for each stocking at each trial at top height 36 m. As has already been indicated, there are dangers implicit in such an extrapolation, possibly more so for the highest stockings which have a greater likelihood of competition-induced mortality over the next few years. Table 5 contains these basal area estimates.

TABLE 5: ESTIMATES OF NET BASAL AREA (m^2/ha) AT TOP HEIGHT 36 M

	Stocking (stems/ha)				
Trial	*111-132*	*178-227*	*237-287*	*290-330*	*345-425*
Whakarewarewa		45.8		56.5	59.2
Tarawera		40.8			57.6
Waratah Cpt 5	33.7	39.4			
Kaingaroa — R911		44.6			
— R680		43.6			51.4
— R681		39.4		44.6	49.1
— R488		41.0			44.3
— R694		40.5	39.8	43.3	43.8
Mangatu R1103		43.7			
R1106		59.7			84.8
R1118		56.3			
Mohaka Cpt 25		45.5			
Cpt 54		33.0			
Gwavas Cpt 29		63.4			
WN216		58.2			
Cpt 65			57.9		
Ngaumu			54.0	63.7	
Te Wera		40.7	46.1		47.8
Santoft		58.4			59.1
Golden Downs NN278	24.8	32.9	38.5		49.4
NN300		42.6			
Otago Coast		43.7			

(Plots second-log pruned excluded)

DISCUSSION

Consideration of the basal area projections in Tables 4 and 5 suggests that the growth projections for the direct sawlog regime in both Fenton *et al.* (1968) and Fenton (1972) were over-optimistic for the Rotorua region. The alternatives are obvious — either a longer rotation to meet the specific end-products implied in the direct sawlog regime, or acceptance of a smaller mean tree than originally projected. However, such questions cannot be resolved without basic defect-core/tree-size relationships. These relationships are lacking for all regimes including those for direct sawlogs.

Some validation of the conclusions reported here has been provided by C. J. Mountfort (pers. comm.) who carried out a utilisation study in Cpt 1099, Kaingaroa Forest. The stand had been planted at 1.8 $\times$ 1.8 m spacing in 1947, low and high pruned in 1956-7, and waste thinned to 198 stems/ha in 1957-8 at an approximate top height (according to compartment records) of 15 m. In 1973 at top height 35.9 m, it was clearfelled. Basal area was assessed at 40.9 m^2/ha with a mean tree diameter of 51.3 cm. There was no evidence of mortality. This assessment compares with the basal area of 43.8 m^2/ha estimated at 35.9 m top height using the linear regression of Table 3 based on the nine, Rotorua, planted, butt-log-pruned plots. It should be noted that thinning of the Kaingaroa compartment was delayed. Regenerated plots used in this analysis, which had similar early high stockings, give an estimate of 40.7 m^2/ha basal area at 35.9 m top height.

For the short-rotation sawlog regime on site index 29 m using the starting value of 4.7 m^2/ha at 10.7 m (as in Fenton, 1972), the Kaingaroa Growth Model predicts a basal area of 44.8 m^2/ha at top height 36.1 m. No mortality is predicted and the estimated mean diameter is 53.7 cm.

Only a small portion of the data used in this analysis was used in developing the Kaingaroa Growth Model. That model was based on Kaingaroa and Tarawera Forest measurements up to 1974. None of the data used in this analysis were available for the construction of the Beekhuis yield prediction method, which was based on plots from throughout New Zealand (Beekhuis, 1966).

In making comparisons between the original growth projections and projected plot data it must be remembered that the original projections are for a specific regime whereas the plots do not necessarily conform in every detail to that regime. For example, the direct sawlog regime prescribed thinning at top heights 4.9 m and 10.7 m whereas the plots were generally thinned only once, with the time of thinning ranging between top heights 9.0 and 15.8 m. Delayed thinning could be expected to reduce the level of basal area growth compared with the prescribed regime. Had all plots received the thinning prescribed at 4.9 m height under the direct sawlog regime, an increase in the level of basal area growth could be expected. Such an allowance has not been included in the estimates shown in Table 4. It should also be appreciated that nutrient cycling by grazing livestock may have enhanced the growth of all but one of the plots which were second log pruned.

For the Rotorua region the Kaingaroa Growth Model better estimates the growth of radiata pine grown under the direct sawlog regime than does the Beekhuis prediction method. However, the Beekhuis method, with little or no modification, provides a good description of stand growth in some other regions. Certainly for plots at Mangatu, Gwavas, and Santoft forests the original estimates of growth calculated in Fenton (1972) are being closely observed to date. The reasons for such regional variation in growth are unknown. One possible explanation is that needle-cast fungi such as *Dothistroma pini* and *Naemacyclus minor* may be affecting basal area growth, even in apparently healthy stands such as those used in this analysis.

It appears that for top heights in excess of 18 m a slope of about 1.66 gives a reasonable average estimate for the relationship of basal area increment to top height increment for the direct sawlog regime, in the Rotorua region. However, the average slope of the four Mangatu plots thinned to about 200 stems/ha (excluding R1103) was 2.20, that of the four Gwavas plots was 2.33, while that of the Santoft plot was 2.30. Projected stand basal area at top height 36 m varies for these three forests between 56.3 and 63.4 m^2/ha. These compare closely with the projection in Fenton (1972) of 58.9 m^2/ha at top height 34.5 m.

The Ngaumu Forest plot with 247 stems/ha has a slope of 2.08 and projected growth of 54.0 m^2/ha at top height 36 m, indicating that growth trends at this forest are similar to those of Mangatu and Gwavas forests.

The projected basal areas at top height 36 m for the Mohaka, Te Wera, Golden Downs, and Otago Coast forests lie within or beneath the range of basal areas projected for the Rotorua region.

The relationship between basal area increment and top height increment, while appearing to be reasonably stable within a region, varies between regions. While the plots at Mangatu and Gwavas show a slow height growth as indicated by generally low site indexes, their basal area development is not retarded to the same extent as the Rotorua plots.

Plots at stockings between 345 and 425 stems/ha have been analysed only when they were in the same trial as plots thinned to about 200 stems/ha. At the 10 trials at which it was possible to compare the growth of 178-227 stems/ha and 345-425 stems/ha the relativity is extremely variable. The average difference in projected basal area at top height 36 m between the two stockings was 10.6 m^2/ha, varying between 0.7 and 25.1 m^2/ha. With such variability this mean difference is of limited value for comparative purposes.

CONCLUSIONS

(1) Growth trends as indicated by the relationship of basal area to top height varied widely between regions; illustrating the likely need for regional growth models.

(2) In the Rotorua region a slope of 1.66 appears to define reasonably well the average long-term trend of basal area on top height for direct sawlog regime stands. Long-term growth trends of first- and second-rotation stands (*i.e.,* planted and regenerated) indicate no significance difference in slope. An estimate of 39-46 m^2/ha basal area at top height 36 m appears reasonable. The Kaingaroa Growth Model better predicts the growth of these stands in the Rotorua region than does the Beekhuis yield prediction method.

(3) A slope of between 2.2 and 2.3 for the relationship of basal area to top height is more appropriate for stands at Mangatu and Gwavas forests. Basal area at top height 36 m is likely to be in the range 56 to 64 m^2/ha. The same could apply to Ngaumu and Santoft forests. Growth trends are generally well described by the Beekhuis method.

(4) The relativity of different stockings varies considerably over the different trials. An in-depth analysis for stockings of 345-425 stems/ha is suggested.

(5) The choice of final-crop stocking cannot be derived from consideration of yield alone. Full economic analysis will also require an understanding of how final-crop stocking affects such factors as mortality and timber grades. Until

a more complete understanding of such relationships is obtained, the question of "What final-crop stocking?" cannot be resolved from either a physical or a financial viewpoint.

ACKNOWLEDGEMENT

The authors gratefully acknowledge the many people who either provided basic data for this analysis, or commented on the manuscript.

REFERENCES

Beekhuis, J., 1966. Prediction of yield and increment in *Pinus radiata* stands in New Zealand. *N.Z. For. Serv., For. Res. Inst. Tech. Paper No. 49.*

Burkhart, H. E.; Tennent, R. G., 1977. Site index equations for radiata pine in New Zealand. *N.Z. Jl For. Sci., 7* (3): 408-16.

Fenton, R., 1972. Economics of radiata pine for sawlog production. *N.Z. Jl For. Sci., 2* (3): 313-47.

Fenton, R.; Sutton, W. R. J., 1968. Silvicultural proposals for radiata pine on high quality sites. *N.Z. Jl For., 13* (2): 220-8.

Fenton, R.; Grainger, M. B.; Sutton, W. R. J.; Tustin, J. R., 1968. Profitability of *Pinus radiata* afforestation — short rotation sawlogs. *N.Z. For. Serv., Res. Inst., Silv. Rep. No. 112* (unpubl.).

Fenton, R.; James, R. N.; Knowles, R. L.; Sutton, W. R. J., 1972. Growth, silviculture and the implications of two tending regimes for radiata pine. *Proc. N.Z. Geog. Soc., 7th Geog. Conf.*

Penistan, M. J., 1960. Thinning practice. *Forestry, 33* (2): 149-73.