PRUNING RESULTS FROM 2.44-, 4.27-, AND 5.49-M PRUNED 19-YEAR-OLD RADIATA PINE

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ABSTRACT

Timber grade results from 25-mm thick boards from 24 pruned and 12 unpruned butt logs of **Pinus radiata** D. Don from a 19-year-old regenerated stand thinned twice to a final crop stocking of 392 stems/ha and pruned in three lifts to **c.** 6 m, were obtained for 2.44-, 4.27-, and 5.49-m log lengths. Log taper was unaffected by pruning. The defect cores were extensive in pruned trees, and bark crescents above steep-angled branches were the worst defects in the unpruned trees. The greatest gain from pruning was the increase of cuttings (Factory) grade, except in the 2.44-m logs where the highest recoveries of clears (13 to 27%) were obtained.

Pruning costs to 5.5 m and compounded at 10% were from $1.37 to $1.77 for trees of from **c.** 31 to 54 cm final diameter at breast height, respectively. Pruning to 4.27 m was generally the most profitable lift; internal rates of return were from 8.8 to 17.6% for trees of these diameters.

Resin pockets, not obviously connected with pruning, were common in four trees and can confound other grade conclusions.

INTRODUCTION

Clearwood yields from sawlogs of radiata pine (*Pinus radiata* D. Don) which had been pruned in two steps to about 5.5 m have been published (Fenton, 1967a; Fenton, Sutton and Tustin, 1971). The pruning operations in the first study were much later than in current schedules; in the second study they were still about 2 years later than in current operations. The final pruning height and the log length investigated in both studies was about 5.5 m. A tree diameter at breast height (d.b.h.) of over 58 cm appeared to be necessary to obtain yields of clears and clear cuttings of the order of 0.5 m^3 sawn per 5.5-m log.

Specialised silvicultural proposals were made to accelerate the attainment of these large diameters (Fenton and Sutton, 1968; Fenton, 1972a) on good quality sites (site index of 27.5 m or over — Lewis, 1954). These proposals defined technical rotations incurring little or no production thinning, and aimed at concentrating growth onto final crop stems relatively early (by 11 m top height). The profitability of the proposals was tested (Fenton, 1972b), as was the profitability (Fenton, 1972c) of earlier defined, similarly-theoretical, technical rotations (Ure, 1949) which had the same number of final-crop stems/ha, of similar diameter and pruned to the same height.

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Other technical management possibilities were defined and evaluated, particularly for the export log trade (Fenton and Dick, 1972). The latter covered lower site indices but, although further work also considered use of lower quality sites for Framing production (Fenton, 1971), no comprehensive guides for regional silvicultural regimes and end-products have been compiled in New Zealand. One possibility is pruning to a lesser final height than 5.5 m, which could apply both to the smaller final-crop trees likely on lower site indices, and as a feasible variation on the export-log regimes. A further reason for testing different pruning heights is that the largest State forest — Kaingaroa — currently (1976) has a silvicultural regime which includes three-lift pruning to 6.1 m and a projected final-crop d.b.h. of 48.25 cm (D. A. Elliott, pers. comm.); it appears possible that a lower final pruning height would be acceptable there. Further data on pruning results are required to help evaluate these and other regimes.

Hence, the yield of clears, clear cuttings, and other grades from the pruned logs of trees primarily in the 30- to 50-cm d.b.h. range for each of the 0/2.44-, 0/4.27- and 0/5.49-m pruning heights are investigated in this study, as another step in evaluating silvicultural regimes*.

METHODS

1. Stand Selection and Description

All North Island State forest radiata pine stands which had received the earliest-timed pruning in the period 1950-63 were inspected, and a final choice was made of a stand in Kaingaroa Forest, Compartment 1219. Details of the stand are given in Table 1, together with present-day pruning lifts. Figure 1 shows current stand characteristics; some trees have incompletely pruned or unpruned butt logs. The site index of 32.6 m (Lewis, 1954) based on a stand age of 19 years (this is always subject to the chance of different ages in regenerated stands) is close to that of the earlier pruning studies — 31.4 m (Fenton, Sutton and Tustin, 1971) and 30.5 m (Fenton, 1967a). It should be noted that no North Island stands of the 1950-63 age classes had received earlier pruning which would have produced small-diameter defect-cores. The Kaingaroa stand was chosen in preference to others at Kaingaroa and also at Waitangi, Glenbervie, Rotoehu or Waitarere Forests primarily as pruning to 2.44 m had been recorded as 1 or 2 years earlier; pruning had been in three lifts (and the actual costs of logging for the study were lower).

2. Stem Selection

The pruned stems taken for sawing were all pruned to at least 5.7 m and were nominally of normal form. Trees were grouped into four d.b.h. classes, <34.4, 34.4-39.4, 39.5-44.4 and >44.4 cm, and larger trees were sampled more intensively than small ones. A few trees in the stand were either unpruned (four trees) or pruned to only 1.8 m; these were taken as "controls". The "control" results were favourably biased by the

* The stand treatment, grading rules and earlier pruning studies are based on Imperial measurements; conversions are used here. The different figures used at c. 5.5 m reflect three different variables: (a) the timber length graded was (up to) 5.49 m long; (b) the log length cut was 5.51 m long, to allow some tolerance in milling; (c) the pruning lifts are the least precise, of course, so are rounded at the third lift.

TABLE 1—Stand history — Kaingaroa Compartment 1219*

Pruned to	2.44 m, using Porter pruners
at age	5 yr
at top height	7.6 m† (cf. Kaingaroa, 1975: 6.1 m); 5.5 m‡
stems/ha	988
Second pruning to	4.27 m, using pole saws
at age	7 yr
at top height	10.7 m† (cf. Kaingaroa, 1975: 9.1 m); 9.5 m‡
stems/ha	296
Third pruning to	6.1 m, probably using pole saws
at age	10 yr
at top height	15.2 m (†) (cf. Kaingaroa, 1975: 12.2 m); 15.3 m‡
stems/ha	198 to 247
Thinned to	938 stems/ha (to waste) at age 5 yr
Second thinning to	445 stems/ha at age 11 yr

Assessment data, April 1975 (§)

Stems/ha	392 (viz, 12% under prescription)			
Basal area/ha	33.129 m^2			
Top height	31.49 m			
Mean tree d.b.h. (o.b.)	32.8 cm			
D.b.h. distribution by number of stems	14-20 cm	5%		
	21-30 cm	34%		
	31-40 cm	48%	<34.4cm	60%
	41-50 cm	12%	34.4-39.4 cm	24%
	50+ cm	2%	39.5-44.4 cm	13%
			>44.4 cm	3%
Largest tree measured	54.0 cm			

(*) Ring counts of stumps showed the trees, regeneration established 1956, were age 17-19 years to winter 1975.
(†) From Lewis, 1954 — assuming trees are 19 years old.
(‡) From Goulding, 1975 — assuming trees are 19 years old.
(§) Based on eight 0.06-ha plots.

pruning the trees had received, and the effect of this was isolated. The numbers of pruned trees in the four diameter classes were 4, 4, 6 and 10; 2, 2, 3 and 5 "control" trees were taken. In fact, one pruned tree in the 34.4- to 39.4-cm class and one "control" tree in the <34.4-cm class were found to be butt swept, and their results are isolated where necessary. Details of the trees sawn are given in Table S1*.

* Tables with S-numbers are in a supporting supplement available from the editor on request.

FIG. 1—Interior of Compartment 1219, regenerated 1956 and photographed summer (December) 1975

3. Logging and Milling

All logs cut were 5.51 m long. Log volumes were calculated, on the advice of J. C. Ellis (Mensuration Section, Forest Research Institute), as:

$$\frac{\pi}{4}\left[\frac{(D_{BE}^2 + D_{1.5}^2 + D_{BE}D_{1.5})\ 1.5}{3} + \frac{(D_{1.5}^2 + D_3^2)\ 1.5}{2} + \frac{(D_3^2 + D_{SE}^2)\ 2.51}{2}\right]$$

where D_{BE} = Diameter at big end,

$D_{1.5}$ = Diameter at 1.5 m,

D_3 = Diameter at 3 m, and

D_{SE} = Diameter at small end (all diameters being under-bark).

Only butt logs were studied.

Sawing was done at the Timber Industry Training Centre mill at Waipa, Rotorua. Logs were sawn exclusively to 25-mm thick boards. The pruned logs were sawn until a defect appeared in the 0/2.44-m section; the logs were then turned 180° and the process was repeated. The remainder of the log was subsequently reduced to a cant of commercial width (if it had not been produced already) for subsequent board production. Cutting was done largely by a vertical band headrig, fed by a Pacific carriage. A circular bench resaw was used for edging to produce final-width timber in the lower 2.44 m only.

The "control" logs were sawn to the standard cants shown in Table S1. Only excessive wane (= absence of wood) at the top end of boards was physically docked. So a characteristic board produced from towards the outside of a log would be physically edged in the lowest 2.44 m, and wany above this point.

All boards sawn were individually identified in the mill.

4. *Grading*

Heights equivalent to 2.44, 4.27 and 5.49 m above stump were marked on boards. (The pruning lifts in the logs studied were found to be at least to these heights.) Then full docking (trimming) was marked (if needed); this procedure avoids bias in subsequent grading. The docking was marked to eliminate wane, not to upgrade timber.

Timber was graded in 0/2.44-, 0/4.27- and 0/5.49-m steps; the shortest length tallied was 1.829 m. Grading was based on the National Timber Grading Rules (N.Z. Standards Institute, 1971), with the addition of clears, that is timber free of all defects. Factory grade was taken to the nearest 30 cm down. All clear cutting lengths of 0.305 m or more, in increments of 0.0305 m, were measured for each board. Data were recorded on standard grade-study forms (R. N. James, pers. comm.).

Prices used are given in Table 2. There is no current price for clears; they were valued at $\$13/m^3$ above Dressing grade.

RESULTS

The relationships between d.b.h. outside bark (o.b.) and diameter inside bark (d.i.b.) at stump, 3.0 m, and 5.51 m are shown in Table 3 (a), the log volume/tree d.b.h. (basal area) regressions calculated are shown in Table 3 (b).

The sizes of the timber sawn from the 5.49-m "logs" are summarised in Table 4. (The widths produced from 2.44- and 4.27-m logs had a similar distribution to that shown for 5.49-m logs and their length distribution can be inferred to have an increasing proportion of "full-length" boards).

The sawn timber recovery and the relative grade production from pruned and "control" logs from the four diameter and three log length classes are given in Table 5. Calculated regressions of sawn timber recovery on basal area are given in Table 6 (a).

Calculated regressions of the recovery of clears plus clear cuttings on basal area are given in Table 6 (b), the mean volumes of the clear cuttings available by tree diameter classes and grade are given in Table 7, with the corresponding mean lengths.

Summarised data on the degrading defects of the timber are given in Table S2. The means of the largest knot per log, by diameter and log height class, are given in Table S3. The numbers of boards in which pith occurred are given in Table S4.

Resin pockets not associated with branches, "Ashley-type" resin pockets (Clifton, 1969), were frequent in two pruned and two "control" trees, 157 being

TABLE 2—Price list*

Grade	Thickness (mm)	Width from (mm)	Width to (mm)	Net Value† ($/m³)
BOX	25	50		30.99
		75	125	30.99
		150		33.17
		175	225	34.35
		250	300	35.14
MERCHANTABLE	25	50		38.38
		75	100	32.38
		125		33.47
		150		37.20
		175	225	41.85
		250		45.79
		300		47.48
DRESSING	25	50		57.62
		75	100	52.61
		125		53.09
		150		57.03
		175	200	59.20
		225		61.56
		250		63.93
		300		65.35
FACTORY	25	50		47.56
		75	125	41.56
		150		47.56
		175	200	53.68
		225		56.04
		250		58.41
		300		59.83

* Waipa State Sawmill Wholesale Domestic List, January 1975.
† A 2½% cash discount has already been subtracted.

recorded in these four trees. Details are given in Table S5. Their effect was isolated in the results — that is, they were excluded when giving the pruning results as such, as in Table 5.

The value of the timber per cubic metre of log and per cubic metre sawn is given in Table 8. These results are the values achieved after disallowing pruning benefit in the "controls", that is, where boards from "control" logs showed clearwood which was traceable to pruning, the equivalent defect was substituted. This correction mainly affected the lengths of clear cuttings available. The correction effect on actual grade was found to be slight, as an equally degrading or worse defect was generally present in the same board. As discussed later, further adjustment is made before pruning profitability is calculated. Calculated regressions of value on basal area are given in Table 9. The values calculated for the "controls" in Table 9 include those adjusted to give the same sawn outturn as from the pruned logs.

TABLE 3—(a) Relationship between d.b.h. (o.b.) and diameter inside bark at stump, 3 m and 5.51 m

(b) Relationship between basal area and log volume

Log Height Class (m)	Category	N†	Regression Coefficients b_0	b_1	r^2	Test in Differences between Pruned and "Control" Variance slope	Ratio level
(a) Relationship between d.b.h. (o.b.) and diameter inside bark at stump, 3 m, and 5.51 m							
5.51	Combined	34	6.314	0.770	0.93**	0.93 NS	3.36 NS
3.00	Combined	34	—0.571	0.828	0.94**	0.42 NS	0.46 NS
Stump	Combined	34	13.831	0.942	0.90**	0.06 NS	1.72 NS
For $Y = b_0 + b_1 x$; where Y = d.i.b. (mm), x = d.b.h. (o.b.) (mm), b_i = regression coefficient							
(b) Relationship between basal area and log volume							
Log length (m)							
5.51	Combined	34	—0.006	4.102	0.97**	1.70 NS	0.60 NS
4.27	Combined	34	—0.005	3.258	0.97**	2.50 NS	0.17 NS
2.44	Pruned	23	—0.002	1.984	0.96**		
	"Control"	11	—0.004	2.029	0.98**	6.50*	5.50*
For $Y = b_0 + b_1 x$; where Y = volume (m^3), x = B.A. (m^2), b_i = regression coefficient							

†N = Number of logs
NS = Not significant
* = Significant at 5% level
** = Significant at 1% level

TABLE 4—Timber sizes produced from 5.49-m logs

Log d.b.h. Class	Percentage of Pruned Width (mm): 51-152		178-305		Percentage of "Controls" Width (mm): 51-152		178-305	
	Length (m):				Length (m):			
(cm)	1.8-3.7	4.0-5.49	1.8-3.7	4.0-5.49	1.8-3.7	4.0-5.49	1.8-3.7	4.0-5.49
<34.4	12	80	0	8	10½	89½	0	0
34.4-39.4	13	65	2	20	15	80	0	5
39.5-44.4	8	35	3	54	10	48	3	39
>44.4	10	33	2	55	12	20	2	55

TABLE 5—Mean volume recovery and grade results

Log Height Class (m)	Log Type	D.b.h. Class (cm)	Volumes log (m^3)	Volumes sawn (m^3)	Recovery (%)	Grades (% of log ht class) Box	Merch.	D.	Fact.	Clear
5.49	Pruned	<34.4	0.343	0.170	49	11	31	6	43	8
		34.4-39.4	0.471	0.255	54	12	26	1	50	10
		39.5-44.4	0.570	0.292	51	22	23	3	44	8
		>44.4	0.746	0.445	60	26	14	4	45	11
	"Control"	<34.4	0.290	0.133	46	41	27	17	14½	
		34.4-39.4	0.484	0.255	53	69	9	7	15	
		39.5-44.4	0.519	0.263	51	54	24	9	13	
		>44.4	0.730	0.401	55	66	11	4	19	½
4.27	Pruned	<34.4	0.271	0.142	52	8	32	10	40	11
		34.4-39.4	0.371	0.204	55	11	23	0	49	16
		39.5-44.4	0.449	0.251	56	19	22	8	36	14
		>44.4	0.591	0.357	60	20	15	4	42	18
	"Control"	<34.4	0.231	0.106	46	37	26	17	20	
		34.4-39.4	0.385	0.218	56	60	14	11	15	
		39.5-44.4	0.416	0.227	54	53	19	13	15	
		>44.4	0.582	0.328	56	58	13	5	23	
2.44	Pruned	<34.4	0.166	0.082	49	2	46	27	11	13
		34.4-39.4	0.230	0.113	49	9	47	0	17	27
		39.5-44.4	0.274	0.142	52	12	45	6	12	25
		>44.4	0.363	0.207	57	16	39	5	13	26
	"Control"	<34.4	0.144	0.062	43	44	46	10		
		34.4-39.4	0.239	0.125	52	36	30	33	1	
		39.5-44.4	0.257	0.116	45	40	37	22		
		>44.4	0.361	0.184	51	53	33	12	1½	

Merch. = Merchantable Fact. = Factory D. = Dressing

TABLE 6—(a) Relationship between basal area and sawn volume
(b) Relationship between basal area and clears + clear cuttings

Log Height Class (m)	Category	N†	Regression Coefficients b_0	b_1	r^2	Test in Differences between Pruned and "Control" Variance slope	Ratio level
(a) Relationship between basal area and sawn volume							
5.49	Combined	34	—0.06	2.68	0.90**	1.15 NS	1.92 NS
4.27	Combined	34	—0.04	2.12	0.92**	1.50 NS	0.83 NS
2.44	Combined	34	—0.03	1.26	0.90**	1.67 NS	3.00 NS
For $Y = b_0 + b_1 x$; where Y = sawn volume (m^3), x = B.A. (m^2), b_i = regression coefficient							
(b) Relationship between basal area and clears + clear cuttings							
5.49	Pruned	23	—73.03	19.99	0.84**	6.46*	39.73**
	"Control"	11	—28.34	11.15	0.69**		
4.27	Pruned	23	—46.26	16.05	0.83**	2.80 NS	31.14**
	"Control"	11	—40.10	10.69	0.57**		
2.44	Pruned	23	—29.01	9.14	0.81**	8.34**	83.12**
	"Control"	11	—14.03	3.77	0.40*		
For $Y = b_0 + b_1 x$; where Y = clears + clear cuttings ($m^3 \times 10^{-3}$), x = B.A. (dm^2), b_i = regression coefficients							

†N = Number of logs
NS = Not significant
* = Significant at 5% level
** = Significant at 1% level

TABLE 7—Mean volumes and lengths of clear cutting

Log Height Class (m)	Log Type	D.b.h. Class (cm)	Volumes ($m^3 \times 10^{-3}$) Timber Grade Box*	Merch.*	D.	Fact.	All Knotty Grades	Lengths (m) Timber Grade Box*	Merch.*	D.	Fact.	All Knotty Grades
5.49	Pruned	<34.4	1.5	1.9	2.6	3.0	2.6	0.59	0.50	0.86	1.05	0.86
		34.4-39.4	2.2	3.7	5.7	4.1	4.0	0.56	0.99	2.19	1.13	1.10
		39.5-44.4	3.0	3.4	4.5	5.4	4.6	0.80	0.68	1.49	1.35	1.14
		>44.4	3.5	3.0	5.4	5.3	4.6	0.73	0.67	1.61	1.25	1.09
	"Control"	<34.4	2.1	1.8	1.9	1.5	1.8	0.72	0.92	0.66	0.69	0.70
		34.4-39.4	2.7	2.8	2.6	2.9	2.7	0.70	0.81	1.00	0.88	0.79
		39.5-44.4	2.3	2.6	2.1	3.1	2.5	0.56	0.63	0.61	0.78	0.63
		>44.4	2.7	2.6	2.4	4.5	3.0	0.62	0.64	0.83	1.06	0.75
4.27	Pruned	<34.4	1.5	2.0	3.2	3.0	2.6	0.57	0.60	1.03	1.09	0.90
		34.4-39.4	—	4.0	—	4.5	4.3	—	1.22	—	1.13	1.15
		39.5-44.4	3.1	3.3	4.3	5.8	4.6	0.70	0.64	1.31	1.39	1.09
		>44.4	3.5	2.8	5.6	5.0	4.5	0.62	0.68	1.37	1.12	0.99
	"Control"	<34.4	1.8	2.1	1.9	1.9	1.9	0.66	0.77	0.69	0.75	0.71
		34.4-39.4	2.8	2.3	3.0	2.8	2.8	0.72	0.65	1.11	0.72	0.82
		39.5-44.4	2.7	2.6	2.2	2.4	2.5	0.64	0.71	0.56	0.72	0.65
		>44.4	2.8	2.3	2.2	4.5	3.0	0.63	0.68	0.73	0.99	0.73
2.44	Pruned	<34.4	—	2.2	2.7	3.6	2.5	—	0.75	0.83	1.32	0.84
		34.4-39.4	2.5	3.3	—	5.0	3.5	0.54	0.78	—	1.28	0.83
		39.5-44.4	2.5	3.0	4.2	8.9	3.6	0.54	0.62	1.08	2.12	0.82
		>44.4	3.2	3.2	3.9	5.2	3.6	0.64	0.68	0.97	1.18	0.80
	"Control"	<34.4	1.9	4.0	1.4	—	1.9	0.68	1.07	0.57	—	0.67
		34.4-39.4	1.9	2.4	2.0	—	2.0	0.49	0.61	0.69	—	0.63
		39.5-44.4	2.3	2.5	1.7	—	2.2	0.57	0.62	0.49	—	0.57
		>44.4	2.5	2.3	2.0	2.7	2.4	0.60	0.60	0.75	1.23	0.68

Merch. = Merchantable
D. = Dressing
Fact. = Factory
* Excluding boards containing pith

TABLE 8—Unit timber values

D.b.h. Class (cm)	0/2.44 "Controls"	0/2.44 Pruned	0/4.27 "Controls"	0/4.27 Pruned	0/5.49 "Controls"	0/5.49 Pruned
			$/m³ of logs*			
<34.4	17.43	22.50	17.22	23.11	16.86	21.55
34.4-39.4	21.67	23.45	20.44	26.00	18.86	24.63
39.5-44.4	19.33	25.55	21.15	27.11	19.44	24.61
>44.4	20.11	28.33	22.87	30.12	21.50	28.25
			$/m³ sawn			
<34.4	40.48	45.55	37.55	44.10	36.77	43.47
34.4-39.4	41.44	47.73	36.10	47.29	35.80	45.49
39.5-44.4	42.84	49.30	38.77	48.50	38.07	48.04
>44.4	39.45	49.67	40.58	49.86	39.15	47.36

(Log Height Class (m))

* Actual results; no adjustment for differences in recovery percentage

TABLE 9—Relationship between basal area and value

Log Height Class (m)	Category	N†	Regression Coefficients b_o	Regression Coefficients b_1	r^2	Test in Differences Between Pruned and "Control"‡ Variance slope	Ratio level
5.49	Pruned	23	—4.681	1.398	0.88**		
	"Control"‡	11	—4.203	1.205	0.82**	0.81 NS	8.58**
	"Control"§	11	—3.684	1.086	0.83**		
4.27	Pruned	23	—3.717	1.170	0.88**		
	"Control"‡	11	—3.529	1.012	0.74**	0.63 NS	8.05**
	"Control"§	11	—3.336	0.941	0.76**		
2.44	Pruned	23	—2.095	0.671	0.82**		
	"Control"‡	11	—0.364	0.473	0.70**	2.38 NS	5.77*
	"Control"§	11	—0.184	0.413	0.68**		

For $Y = B_o + B_1 x$; where Y = value ($), x = B.A. ($m^2 \times 10^{-2}$), b_i = regression coefficient

†N = Number of logs
‡ = With volume adjustment
§ = Without volume adjustment (i.e., as measured)
NS = not significant
* = significant at 5% level
** = significant at 1% level

DISCUSSION OF RESULTS

1. Log Volumes and Taper

Outside New Zealand, differences in stem taper in pruned pine species have been recorded in the first 2 to 5 years after pruning (Young and Kramer, 1952; Møller, 1960; Adlard, 1969). It has been stated "Pruning was associated with a reduction in taper in all the tests in which taper changes were measured, substantial changes in taper being recorded" (Fielding, 1964). A later study on *P. strobus* L., 27 years after pruning of dead branches, showed no difference in taper (log d.b.h. and small end diameter — s.e.d.) between 4.88-m long pruned and unpruned logs of mean s.e.d. 45.3 to 47.4 cm (Calvert and Brace, 1969).

Measurements in local radiata pine, in contrast to most of the results mentioned above, showed that if any differences in log taper followed green-branch pruning they were soon eliminated by subsequent growth (Sutton and Crowe, 1975). Results of the present study, taking the relationship between d.b.h. and diameters at stump, 3 m, and 5.51 m as an expression of taper, also showed no significant differences in stem taper between pruned and "control" trees. (For completeness the relations between the respective diameters at 3 m and 5.51 m were tested; their levels differed significantly at the 99% confidence limits — that is, the diameters diminished in this height interval.)

There were no significant volume differences between pruned and unpruned logs per d.b.h. class for 4.27- and 5.51-m long log classes (at the 5% level). The differences in volume in the 2.44-m long logs were significant at the 5% level, and approached the 1% level. This would seem to infer that the stem section which had been pruned for the longest time had the only significant difference in volume. But the differences in volume over the range of diameters studied are of no practical importance.

It is feasible that the differences in volume in the 2.44-m lengths are influenced by the greater variation caused by proximity to the stump. The bulk of the literature deals with variation in stem taper (often called "form") for a relatively few years after pruning; the present study gives results which are proportionately late in the rotation. This may account for the differing results. For greater sawn timber recovery and more uniform wood properties, it would be desirable to produce as cylindrical a trunk as possible, but pruning in the sample studied did not appear to have affected taper.

2. *Sawn Timber Recovery*

The trends in mean sawn-timber-recovery percentage (conversion factors) are relatively consistent (Table 5), with generally greater percentage recovery with an increase in log diameter for all log lengths for both pruned and "control" classes. However, the recovery percentage of the 34.4- to 39.4-cm diameter "controls" was better than the trend.

The calculated regressions of timber recovery per tree basal area (Table 6 (a)) showed there were no statistical differences between pruned and "control" logs. This is presumably because of large variability and the small sample number. The differences in the volume of sawn timber obtained are such, however, that they formidably increase the value of sawn outturn of the pruned logs. Pruning profitability, therefore, was calculated on the basis that the same sawn volume was obtained from the corresponding diameter classes of the pruned and "control" trees. (The alternative methods of treating this difference in sawn volume include giving results at each volume obtained at the 95% confidence limits, which gives four sets of figures, or, as there are no significant differences in recoverable volume, taking the combined regression (average recovery) — C. J. Goulding, pers. comm.)

The question of conversion factor (or sawn recovery percentage) was discussed earlier (Fenton, 1967a), when logs up to 49 cm s.e.d. were sawn. This earlier study showed that, when boards not wider than 304 mm were sawn, recovery percentage hardly increased, while log s.e.d. (of 5.5-m logs) rose from 35 to 49 cm. The s.e.d. of the largest logs in the present study were 41-42 cm and, in view of the 1967 results, no increase in recovery percentage should be anticipated for larger logs, if sawing is of 25-mm thick boards to a maximum width of 304 mm.

Earlier grade studies of logs of these diameters (Fenton *et al.,* 1971; Fenton, 1967a), showed similar results although they were from log positions which were higher up the trees, where taper generally favours relatively high percentage recovery of timber. In the current study the higher recovery from pruned as against "control" logs is presumably a reflection of poorer form — viz. deviation from a straight axis — in the unpruned trees. The potential loss of volume by breakage of boards at gross-sized defects was not observed to be of any importance in the milling during this study. The appropriate allowance to make for differences in recovery in calculating pruning profitability is considered later. By local commercial standards the overall 50-60% recoveries are high.

The highest relative recovery is from 4.27-m log lengths. But the study method — using 5.51-m logs and marking the positions of different length boards — possibly affected the potential recovery from the shorter log lengths, and it could be argued that recovery percentage from 2.44- and 4.27-m long logs, cross-cut and sawn as such, would be higher than shown here. The point is of some importance as the lower pruning lifts are easier to make, and should tend to give greater returns per unit volume. But no adjustment for potentially greater recovery has been made in calculating values for 0/2.44- and 0/4.27-m pruning.

3. Timber Sizes Sawn

The volume recovery and the sizes sawn are of fundamental importance in any sawing study (Fenton, 1967b). For example, higher overall recovery of large-sized timber resulted in a greater value per cubic metre of log from late-pruned (Fenton, 1967a) than from well-pruned (Brown, 1965) radiata pine of similar log size. Calculations of pruning profitability have to treat recovery carefully; it is feasible that extra sawing operations to recover clearwood will legitimately reduce volume recovery, while increasing total values.

In this study all timber was sawn to 25-mm thickness, partly to facilitate the identification of pruning and defect characteristics. Radiata pine of this age (19 years) is still not producing wood of maximum density (Harris and Nash, 1972), and framing (50-mm thick) timber quality would be affected by this as well as by the small log size. A study including pruned logs from thinnings (Sutton *et al.,* 1971) in which both 25- and 50-mm thick material was produced from 23-year-old trees of smaller size (33- to 35-cm d.b.h.) than in Compartment 1219, showed 23% higher values from sawing to 50-mm thickness than to 25-mm. But about 20% of the 50-mm material was in 127-mm and 152-mm widths, while less than 12% of the 25-mm material was sawn even as wide as 200 mm, and the lack of width availability (for 25-mm boards) in these small logs would have influenced the results. Further, the framing timber was graded visually. Some local experience in stress-grading young radiata pine is recorded. A limited sample of 25 pieces from 19-year-old thinnings was stress-graded and five were below the visual grade (Tustin and Knowles, 1970); this timber was not necessarily from butt logs. A study which included 20 pruned butt logs from trees of mean d.b.h.

c. 56 cm, age 25, gave a 76% yield (of the 50-mm timber) of No. 1 framing grade from visual grading (Knowles and James, 1973), but machine grading results were not recorded.

There are few other grade results available from sawing butt logs of this size and age to 50-mm thickness, and it is feasible that the unpruned "controls" would have higher unit values from 50-mm than from 25-mm sawing. On the other hand, there is the possibility of obtaining greater returns from pruned logs by sawing 18- or 20-mm thick boards from the outer part of the log. These thicknesses are sold in the Baltic countries, for example. It is also feasible to saw the pruned logs to 50-mm thickness. Indeed, if the plantation concept of directed silviculture is to be properly established as the fundamental principle in making local forestry profitable, a whole series of such studies is required on different-aged stands, testing the interaction of the geographical density trends, pruning intensity, and stand-stocking variation on 25- and 50-mm thickness timber. Such research has guaranteed results and would reduce avoidable guesswork by management.

If silvicultural schedules revert to the approximate pruning steps given to Compartment 1219, a feasible sawing pattern for the pruned logs would be:

Centre: three 25-mm boards. This zone is the lowest grade corewood in the tree, of minimum density and relatively high shrinkage which, with the concentration of knots, would produce low-grade framing timber. The outer parts of the wide 25-mm boards could be re-ripped if any cuttings are available.

Adjoining 50 mm: to framing timber. This would incorporate many of the actual pruned branch stubs; presumably an occlusion scar would be a less serious defect than the parent knot. The defect produced immediately beyond the pruned stub usually degrades a 25-mm board to Merchantable or Box (unless or until defects are sufficiently far apart to recover cuttings or factory grade).

Outer zone: to 20-mm boards for cuttings and eventually clears.

In this study both the pruned and the "control" logs were sawn to produce wide boards. Local price lists have shown an increasing margin for width, especially in the better grades, and so tend to increase the relative profitability of logs which can produce up to 300-mm wide timber. The slightly greater proportion of wides produced from pruned logs in all but the largest diameter class (Table 4) would favour pruned realisations if grade yields were unaffected. This trend would be reduced by the high proportion of box grade in the "control" logs, which has the least width differential. It is also possible that higher yields of the better grades would be produced from both pruned and "control" logs by sawing narrow boards, as in earlier studies of quarter-sawn butt logs (Fenton, 1967a), but at the cost of width differentials. A check on the order of magnitude of this potential (and problematical) loss in value was made on the 0/5.49-m logs of the 39.5- to 44.4-cm class of "controls", where the sizes sawn showed a 15% lower yield of wides (Table 4). Taking 13% of this in merchantable grade and 2% in box grade, and allowing a mean increase in width from 152 mm to 229 mm, timber values would rise by $0.166, or 1.6%. As this is the greatest difference likely no corrections were made.

These qualifications on the timber thickness and width produced affect pruning profitability. There is also the possibility of increasing total values by appropriate docking, at least of defects near the ends of boards, which was not tested in this study.

With the pruning given Compartment 1219, recovery of clear face veneer in quantity is unlikely, but this remains a potentially profitable outlet for earlier-pruned material.

4. Overall Grade Results — "Controls"

The "control" logs of all three lengths and four diameter classes studied are clearly inferior to the pruned logs. This applies both to the timber grades (Table 5), and to the intrinsic quality as reflected in the distances between defects (Table 7) and the maximum knot size present (Table S3).

The tending (stand stocking) schedule had been successful in keeping branches alive and so avoiding bark-encased knots, as only 3.6% of the timber was degraded by them. But the effect was reduced, in these trees at least, by the bark crescents associated with steep-angled (closer than 40° to the vertical) branches. There is a progressive reduction in dressing grade (apart from the smallest trees) with increasing log length. Grading in this study, as in others, tends to be more severe than in commercial practice and the results probably represent a minimum level.

Factory grade, as defined in the grading rules, has a minimum total length of 1.828 m of clear cuttings per board (in minimum cuttings of 0.61 m), and the factory grade yields of both controls and pruned logs in the 0/2.44 m logs are reduced by this minimum.

Apart from this factory grade effect, however, the longer the log length, the greater the chance of a board containing a critical defect, and the poorer the grade yield of the "controls".

It can be contended that the "controls" represent a stratified sample, being unpruned relics in a selectively pruned and thinned stand. Some, at least, may have had intrinsically poorer butts than the pruned stems. It would not take much improvement in branch angle to transfer some of the box grade to dressing in the "controls" of this study. In the main, evaluation of local silviculture, especially of pruning, has had to wait for the growth of pruned crops; their availability was limited until recently. Now the converse may become a complication in research — a relative shortage of otherwise-equal unpruned stands.

5. Overall Results — From Pruned Logs

Pruned branch occlusion scars, and their parent branches, were the major defects of the pruned logs, largely replacing the knot defects of the "control" logs. It should be stressed that there were few signs of poor pruning or of unduly long scars after pruning; none were more than 5 cm in radial extent.

In timber from the pruned logs with frequent occlusion defects, the degrading characteristics of merchantable grade differ from those of the current commercial grade. When timber from pruned stands becomes a regular part of the commercial log supply, and is not only known to a few research workers, additional defect classifications could be included in the national grading rules.

The differences in the yields of clears plus clear cuttings between pruned and unpruned logs, of the same log length, were highly significant (Table 6 (b)). The major results of pruning, as in earlier examples (Fenton and Familton, 1961; Fenton, 1967a), is an increase in clear cuttings and, *inter alia,* of factory grade. As stated earlier:

"In pruned . . . logs the innermost boards are usually of box grade, then merchantable or dressing further out from the pith; as pruning defects decrease in incidence with increasing distance from the core, all grades give increasing recoveries of clear cuttings, and factory grade yields rise. Ultimately, full-length clear boards are produced; the length of these full-length clears then shortens as the outside limits of the log are reached" (Fenton **et al.**, 1971).

This statement should be modified to cover what happens when longer rotations are involved, as is the case here. The projected felling age for Compartment 1219 is, presumably, age 25-30. The net effect on the timber grade yield (of the butt logs) is not the automatic production of clears outside the present clear zone (except for most of the 0/2.44-m log class). In a 5.5-m log sawn at age 19 a clear board which is, say, 100 × 25 mm and 3 m long, will, if not docked for grade, probably be wider, longer, and of factory grade at age 25-30 as it will run into the defect core at the top of the log. The only grades which invariably stay constant are those from the centre of the tree; the others have a general chance of recruitment into, and improvement within, factory grade from somewhat late pruning of not very straight stems.

It is reiterated that factory grade from pruned logs has relatively high recoveries of longer and bigger cuttings than from the usual commercial grade, but if it is considered to be unsaleable, the case for pruning would be much diminished. Conversely, it could be considered to be worth more than current factory grade, and profitability would be enhanced. Current pruning schedules, which will achieve smaller diameter cores than in Compartment 1219, will result it is thought, in a higher proportion of clear (and possibly a lower proportion of factory) grade.

The quality of the factory grade produced from pruned logs differs in another way from that of the naturally occurring clear cuttings. The occlusion pattern results in grain distortion, which decreases with increasing radial distance from the pruned stub. This distortion has not been a major problem in wood studied so far, but lifting of the grain can occur in dressing (planing) timber. In the interim, the standard price for factory grade has been accepted and used in this study.

The tabulations on the volume and length of clear cuttings per grade and per log length are of application in finger-jointing plants. It is likely that resawing — including ripping — would improve grade recovery.

As discussed earlier, sawing 50-mm thick timber for enhanced framing timber production is feasible, and is apparently a major objective of softwood pruning in South Africa. Framing timber properties are generally improved by increases in density; overseas results tend to report improvement in wood density in logs which have been pruned of live branches, but this appears negligible in local examples. Results obtained from radiata pine trees which had received severe pruning (0 to 5.5 m at 8.5-m top height) coupled with drastic thinning from *c.* 1200 to 200 stems/ha at 8.5-m top height showed:

"The changes recorded in average wood density were small and, if anything, beneficial since they tend to increase the strength properties and pulp yield of the affected part of the corewood. In practice, thinning and pruning treatments in radiata pine would be less severe than those studied here, with the result that any changes in wood properties would also be even less apparent and probably of little technological significance" (Cown, 1972).

As stated earlier, many of these doubts can be resolved by a series of properly executed and planned grade studies on 25- and 50-mm sawing, with ancillary docking studies if necessary, linked with basic wood-property determination. Degrade from pith, and cutting patterns to reduce it, have been dealt with earlier (Fenton and Familton, 1961; Fenton, 1967a), and the low percentage of the pruned logs' timber degraded by pith and associated spike knots is a reflection of the method of recording used in the study, which concentrated on pruning aspects; pith was often an equal cause of degrade in logs over 2.44 m long. In the lowest 2.44 m, however, pith was rarely more than 7-8 mm wide, and hence of less importance than in the higher logs formed during the characteristically more rapid stages of height growth. Pith frequency gives an approximate measure of stem straightness in the early years of growth, and tree straightness is important in obtaining good yields (say 30% plus) of clearwood. Although the trees of Compartment 1219 now appear reasonably straight, the pith incidence shows early form was poorer (Table S4). Understandably, the shorter the log, the less was the general deviation from straightness recorded. But some trees were evidently butt swept in youth, and later stem development obscured this.

The pruning given this compartment was probably within a year of that currently scheduled for the 0/2.44- and 2.44-/4.27-m lifts; the 4.27-/5.49-m lift was approximately 1 year later than a similar one on current schedules. (The long-standing site index of Lewis (1954) should now, presumably, be replaced by the newer, more fully-based figures prepared by C. J. Goulding, 1975.) The results show that there is a high proportion of wood which contains some direct signs of pruning.

The importance of the core and the adequacy of a 4-in. (10.2-cm) sheath of clearwood were expressed long ago:

". . . a thickness of 4 inches is about the absolute minimum (sheath) permissible inasmuch as this margin will invariably be reduced by the actual number of inches lost due to crook, bend, butt-flare, protrusions of the stubs of the pruned branches at the whorls beyond the diameter of the logs invariably measured at inter-whorl points, defective occlusion of the pruned stubs, grain-distortion around the pruned stubs, slabs and sawkerf. There appears to be no justification, therefore, for suggesting that this 4 inches thickness is excessive. On the contrary, it is too low, if anything" (Craib, 1939).

The aim of the later South African pruning schedules was 4- to 6-in. (10- to 15-cm) knotty core, to attain which the pruning schedules had to be steadily revised (Craib, 1947) and made earlier, despite a fundamentally more favourable diameter/height relationship in South Africa than in New Zealand (Fenton, Sutton and Irvine, 1963).

If pruning results in increment loss of final crop trees and prolongs technical rotations, the economic costs rise formidably, and the relative costs and returns of alternative pruning schedules appear to need evaluating. While the few growth plots available are growing, research can proceed in the interim by obtaining the timber grade and value results from the relatively large-diameter core material available from trees pruned in the 1950-64 era.

6. *Timber and Log Values*

Though the subject is raised in most local reports of grade studies of radiata pine, it is necessary to reiterate that the appropriate price to use for clears is not known. While the local market is in the unusual position of having virtual price control — that by agreement between producers having replaced government control *c.* 1965 — no price is quoted for clear pine for the good reason that none has yet been produced. (Local timber prices are not generally high or out of step with, for example, free on board (f.o.b.) prices of equivalent softwoods in North America, despite set price lists here). In this study the margin used of $13/m³ is about 22% higher than the dressing grade price (depending on the width of the board). Dressing grade is the second best of the local knotty grades. Obviously variations in the clears margin affect results, particularly those of the lowest pruning lift which had the highest yield of clears.

There were no significant (95% confidence limits) differences in the slopes of either sets of "control" values against the pruned values for all three log lengths, though there could be for practical purposes (Table 9). The levels were, however, significantly different. The high value of the largest "control" tree was due to its relatively "uninodal" branching whereby 47% factory grade was produced from the 5.49-m log and 65% from the 4.27-m log.

Presentation of actual value gradients in local forestry has been confined to the grade studies quoted (Fenton, 1967a; Sutton *et al.,* 1971). The values of sawn outturn per basal area unit are still only half of the data required for profitability analyses—differential or other demonstrated utilisation costs are also required.

The advantage of concentrating basal area onto larger trees is, however, partly quantified—for 5.49-m logs the following values are available, for example, per 0.2 m² of basal area:

1 large tree — value $23.2

2 trees each 0.1 — value $9.2 × 2 = $18.4

Corresponding margins for 4.27-m and 2.44-m logs are 22½% and 20%.

7. *The Profitability of Pruning*

The profitability of pruning is not found, except in special limiting cases, by comparison of pruned and unpruned logs of the same size and age, but by comparisons of a pruned regime with the most profitable alternative (Fenton, 1967b). However, if for other reasons a given spacing/rotation regime is set for a stand, then one of the special limiting cases applies, and the profitability of pruning can be tested. This assumption is made here in the subsequent calculations. (This assumption implicitly ignores the impact, if any, of green branch pruning on increment; current data (Sutton and Crowe, 1975) show lower basal area increment from pruned trees *remaining in an unpruned* stand, though this can be at least partially compensated for by earlier thinning. It is feasible that a more valid comparison would be between pruned stems and unpruned stems of whatever greater diameter is appropriate. The complications become surprisingly formidable.)

(1) Pruning costs

Only direct charges of labour and tools have been costed. Supervision, transport and overhead items should be costed and allowed for in each calculation; they have been omitted here to simplify the results. Transport (of workers) will be a variable charge in any forest. The figures for contract operations in 1975 at Kaingaroa have been used — viz, pruning costs and timber prices are for the same year. Some calculations of pruning profitability have used pruning as a hedge against inflation (Calvert and Brace, 1969), but this appears to warrant treatment in isolation. The allocation of costs through the tree diameter classes has been taken from work study analyses and is the work of Messrs K. Walker and C. Terlesk.

The next point is to allocate costs per tree. In evaluating Kaingaroa Forest's present regime at the tree heights given in Table 1, 600-700 stems/ha (617 nominally) are 0/2.2-m pruned, but only 371 stems/ha are utilised as pruned stems. So the individual cost per tree for the 0/2.2-m lift is increased by two-thirds to allow for the extra stems pruned and then thinned before useful utilisation (of the pruning). But even this has the implicit assumption that the same proportions of large and small trees are lost. Obviously other regimes may have different cost multipliers. The costs used are given in Table 10.

Interest rates and economic criteria present their own problems; as a principle in these limiting cases, it is useful to calculate the break-even rate. Locally, a minimum of 10% is set by the New Zealand Treasury, and as returns, costs and volumes are easy to isolate in these calculations, the various pitfalls of the correct financial criterion to use can be avoided by expressing results for most or all of them.

TABLE 10—Pruning costs per tree (cents)

	D.b.h. Class			
	Smallest	2	3	Largest
0/2.44-m lift	10.8	11.8	12.4	13.0*
× 1.66†	68.32	74.65	78.47	82.27
2.44/4.27-m lift	12.5	13.8	15.8	17.3
12 years' interest (at 10%)	39.23	43.31	49.58	54.29
Subtotal 0/4.27 m	107.55	117.96	128.05	136.56
4.27/6.1-m lift	12.6	14.1	15.7	17.3*
9 years' interest (at 10%)	29.71	33.24	37.01	40.79
Total 0/5.5 m	137.26	151.20	165.06	177.35

* Extrapolated figures
† To get 617 stems/ha pruned, 14 years' interest at 10%

(2) Returns

The qualifications in using the unpruned trees as "controls" have been discussed earlier; in summary they are:

(a) They have been sawn to similar thicknesses, widths and lengths;
(b) The sawn recovery per diameter class has been adjusted to give the same volume outturn for pruned and unpruned logs.

General qualifications include:

(c) The price lists apply; the grades are saleable;
(d) The log lengths are rigidly set, and are not extended to a better cross-cutting point (e.g., immediately below the unpruned whorl).

There are other benefits from pruning. These include, in increasing order of elusiveness (or difficulty in calculation):

(e) Reduction in tree-trimming cost at felling — this amount has been calculated by C. J. Terlesk as $0.09 to $0.11 per butt log length. Possibly, future felling-machinery may reduce this benefit, and it has been recorded but not used here;
(f) Lessened tending costs by facilitation of access;
(g) Later utilisation benefits, including easier barking and sawing, and more uniform slabwood quality;
(h) No aesthetic benefits are thought to be reasonable for the stand studied, as casual

visitors could be infrequent. There is no reason to disallow them in some localities, nor should their importance be underrated. No other motive seems valid for 80% of the 40 500 ha of plantation first-pruned in State forests.

(3) Profitability

Profitability results, assuming the trees are utilised in year 19, are given in Table 11. Table 11 (a) gives results in terms of the interest rate earned by the pruning of the three log lengths; pruning the largest tree classes can generate relatively high rates of return. The return/cost ratios are given in Table 11 (b), the gross and net returns per tree in Table 11 (c), and net returns per cubic metre of log and per cubic metre sawn in Tables 11 (d) and 11(e), respectively. Table 11 (f) supplies more specific

TABLE 11—Profitability of pruning, mean results, Cpt 1219 age 19

D.b.h. Class (cm)	Log Height Class (m): 0/2.44	0/4.27	0/5.49
(a) By internal rate of return per log (%)			
<34.4	6.2	8.8	8.3
34.4-39.4	9.6	15.6	14.4
39.5-44.4	11.3	15.4	15.1
>44.4	17.7	17.6	16.6
(b) By return/cost ratios per log at 10% interest			
<34.4	0.6	0.9	0.8
34.4-39.4	0.95	1.9	1.6
39.5-44.4	1.2	1.9	1.8
>44.4	2.6	2.4	2.1

(c) By margin per log at 10% interest ($)	0/2.44 Gross	0/2.44 Net	0/4.27 Gross	0/4.27 Net	0/5.49 Gross	0/5.49 Net
<34.4	0.42	—0.26	0.93	—0.14	1.14	—0.23
34.4-39.4	0.71	—0.03	2.29	1.11	2.47	0.96
39.5-44.4	0.92	0.14	2.44	1.16	2.91	1.26
>44.4	2.11	1.29	3.31	1.95	3.65	1.88

D.b.h. Class (cm)	0/2.44	0/4.27	0/5.49
(d) By net margins per m³ of log at 10% interest ($)			
<34.4	—1.27	—0.52	—0.67
34.4-39.4	—0.13	2.99	2.04
39.5-44.4	0.51	2.58	2.21
>4.44	3.55	3.29	2.52
(e) By net margins per m³ of sawn timber at 10% interest ($)			
<34.4	—3.26	—1.02	—1.37
34.4-39.4	—0.32	5.41	3.76
39.5-44.4	0.93	4.63	4.32
>44.4	6.25	5.46	4.23

(f) By net margins per log per pruning lift at 10% interest ($)	Log Height (m): 0/2.44	2.44/4.27	4.27/5.49
<34.4	—0.26	0.12	—0.09
34.4-39.4	—0.03	1.14	—0.15
39.5-44.4	0.14	1.02	0.10
>44.4	1.29	0.66	—0.07

answers for each pruning lift, some of which are curious at first-sight. For example, the second-pruning lift may be profitable (viz, earn more than the set 10%), whereas the first lift may not be. Part of the explanation is that given earlier — more trees are 0/2.44-m pruned than reach clearfelling age; the added cost accrues more years' interest in any case. There is a further effect which has not been isolated in this study — pruning the lower part of a longer log can have a beneficial effect on the whole by removing critical defects and/or supplying further lengths of clear cuttings. The last pruning lift contributed little extra factory grade; most of it was already available in the lower 4.27-m. These extra values are also net expressions of the complex differences between branching frequency and condition between, and up, pruned and unpruned stems of a somewhat variable species.

(4) Applicability of the results to current management

The general case: Four reasons for obtaining results from pruned logs were given in the introduction: (1) to provide data for guidance on lower site indices; (2) to test profitability of pruning to different heights; (3) to see if pruning is justified on export-log type regimes; and (4) to see if Kaingaroa Forest's current regime justifies pruning. The necessary steps to test pruning profit are given in a general form below, followed by a specific example for Kaingaroa Forest, Compartment 1219. These overall limiting cases are where pruning is only a marginal investment.

The steps in the general case are:

(a) Preparation of a standard growth projection based on whatever is the current yield model. At present it appears the earlier yield projection (Beekhuis, 1966) is being replaced, at least as far as Kaingaroa Forest is concerned (Elliott and Goulding, in prep.).
(b) The new yield table does not yet contain a diameter distribution; in the interim the previous one (Beekhuis, 1966) should presumably be used. At this stage the manager should have a given stand diameter distribution at a given age calculated.
(c) The next step is to see how far the pruning steps and costs vary from those in Table 10. The necessary modifications can be made (e.g., for unit costs; number of stems pruned; time of pruning; years to felling). Indirect costs for supervision, transport and overhead should be calculated and compounded for the appropriate number of years.
(d) The differences in unit values can be calculated from Table 10 and grouped by d.b.h. class if necessary, as in Table 11 (c). The differences between net values and compounded cost are then found.

General limitation: A negative result does not necessarily mean pruning does not pay, however, for obviously a butt log from a 42-cm d.b.h. tree at age 30 say, pruned at the ages given in Table 1, will be superior in grade, to at least some degree, to one that size in the present study (and the "control", too, could be better in 50-mm sizes). The yield tables available do not give prediction of growth of given diameter classes; if sufficient directed grade-studies are done it should be possible to calculate value changes.

(5) The Kaingaroa example

The rotation given is between 25 and 30 years, depending on site index, to attain a mean d.b.h. of 48 cm. For illustrative purposes this has been taken as 26 years on the site index of Compartment 1219. (The current regime at Kaingaroa is such that final stocking/ha is lower — 370 c.f. 390 — and is attained 2 years earlier than in Compartment 1219, so diameters will probably be greater than at the same age in the present stand; this qualification does not affect the methodology).

The stem distribution (by diameter classes) and the margins at ages 19 and 26 are given in Table 12. The extra costs in 7 years are close to double (at 10% interest) those at age 19 and this approximation has been used. The results show that pruning can carry a 10% interest charge on direct costs on this rotation, as all except the smallest trees return at least 10% on pruning (about 85% by number).

8. "Ashley-type" Resin Pockets

The effect of resin pockets has not been counted in any of the grade or value results presented. If resin pockets are present in a 25-mm clear board they negate the benefits of pruning, or reduce the board to factory grade; in 50-mm thick timber they would reduce strength but not necessarily be critical. These defects have not previously been of importance in Kaingaroa Forest timber, either in the grade studies quoted or in general sawmill production. Their general incidence in the Bay of Plenty region had previously been reported as "normal", that is, 5 or fewer per cubic metre of timber (Cown, 1973). They were sufficiently frequent at Ashley to reduce pruning operations there (Clifton, 1969); they were also recorded in Ngaumu (Sutton *et al.,* 1971).

The possible causes of the defect are discussed by Cown (1973) who reported they were more frequent in co-dominant or dominant trees. But in Compartment 1219 they were present in all diameter classes, except the smallest unpruned trees. The high incidence in Canterbury has been ascribed to wind (Clifton, 1969), but this was not

TABLE 12—Kaingaroa pruning profitability per tree

D.b.h. Class (cm)	% Stem Numbers — Age 26 Years*	Cost† 1	Cost† 2	Cost† 3	Margin‡ 1	Margin‡ 2	Margin‡ 3
				19-Year ($)			
<34.4	2½	0.68	1.07	1.37	—0.26	—0.14	—0.23
34.4-39.4	13	0.75	1.18	1.51	—0.03	1.11	0.96
39.5-44.4	39½	0.78	1.28	1.65	0.14	1.16	1.26
>44.4	45	0.82	1.37	1.77	1.29	1.95	1.88
		Cost 1	Cost 2	Cost 3	Margin 1	Margin 2	Margin 3
				26-Year ($)			
<34.4	2½	At 10% interest				Negative	
34.4-39.4	13	costs are nearly			—0.78	—0.07	—0.55
39.5-44.4	39½	double those			—0.64	0.12	0.39
>44.4	45	given for 19-year			0.47	0.58	0.11

* Beekhuis (1966) for a mean tree of **c.** 48 cm
† Table 11
‡ Table 12 (c)

1 = 0/2.44-m step
2 = 0/4.27-m step
3 = 0/5.49-m step

considered to be the cause at Ngaumu (K. C. Chandler, pers. comm.). Whatever the cause, they are an unwelcome finding at Kaingaroa. Their presence in both pruned and unpruned stems at least suggests they are not directly related to pruning.

A current project is testing whether bark scar characteristics are indicative of their presence. If this is so, then affected trees can be identified and remain unpruned; similarly, some stands may be identified as sufficiently affected to be not worth pruning. In the interim the frequency of resin pockets should be recorded in any grade study.

The earlier report of a "normal" incidence in the Bay of Plenty region (Cown, 1973) was based predominantly on experience with the "old crop" (pre-1939 establishment) which remained untended. It seems feasible that recent schedules which open up the stand by thinning could increase the trees' susceptibility to cambial lesions, whether caused by wind, frost, drought, sun-scald, or a combination of these or other factors.

9. Management and Research Implications

Local plantation management will have to continue to rely for some time on theoretically derived, rather than demonstrated management prescriptions. The large area of "old-crop" (45 years plus) radiata pine naturally provides considerable data on ultimate tree size, survival rate, and so on, for untended stands but their deliberate recapitulation would be highly expensive. Biological changes, especially those associated with *Sirex noctilio* (F.) and *Dothistroma pini* Hulbary, further complicate extrapolation from earlier experience. The post-1945 plantings have received a variety of pruning and thinning treatments, and provide an increasing range of appropriate-sized material to use to test or evolve management prescriptions. A uniform method of grade study (and the advent of stress-grading machines to check strength results where necessary) should be a fundamental aid in evolving these prescriptions. The process can be accelerated by allocation of the requisite research effort, and by identification of stands which had received earlier pruning than Compartment 1219, and which are large enough to test. These stands may be available in company-owned and private forests.

Indications from this study are that pruning is more profitable if the same basal area is carried on fewer stems rather than more. The "control" trees also have a marked positive value gradient. As there appear to be few results available from overseas on pruning, and the total local effort rests on results from approximately 60 logs, it is desirable to obtain better basic information on log values. Attempts to apply sophisticated computer techniques while these and other basic data remain unquantified are likely to lead to strange results.

CONCLUSIONS

In this study:

1. There are negligible differences in log volume per unit of basal area of the pruned and unpruned logs, in the 4.27- and 5.49-m length classes.

2. There are statistically significant differences between log volume per basal area of the pruned and unpruned logs in the 2.44-m long logs, but these are of no practical importance.

3. There are negligible differences in taper between pruned and unpruned logs.

4. Pruning has improved grade recovery of 25-mm thick timber.

5. The most frequent improvement from pruning is the increase in clear cutting (factory grade), except in 2.44-m long logs.

6. Returns on pruning were highest for the 0/4.27-m logs, if trees are felled at age 19; they exceeded 10% on all but the smallest logs.

7. The third pruning lift from 4.27 to 5.49 m had not generated a 10% return, except for one diameter class.

8. Resin pockets, not obviously connected with pruning, can confound other grade conclusions.

9. Specific provisions for pruning occlusion defects are probably required in future national grading rules.

10. Kaingaroa Forest's current regime, assuming the rotation is set for other purposes, can carry a 10% charge on pruning on this site index (33 m) to at least year 26.

11. Research in local plantation forestry should exploit the opportunities now available from an increasing choice of pruned and thinned stands to resolve outstanding timber grade and profitability problems.

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