VARYING SELECTION RATIOS (INITIAL *VERSUS* FINAL CROP STOCKING) IN *PINUS RADIATA* EVALUATED WITH THE USE OF MARVL

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ABSTRACT

The initial stocking trial, 19 years old at the time of assessment, was located in Rotoehu Forest, and incorporated genetically improved stock (with a Growth and Form factor of 13) and unimproved stock (GF3). It was planted at six levels of initial stocking from 250 to 1500 stems/ha, and thinned to 250 stems/ha. Results of the evaluation were adjusted for bias due to microsite.

There was an apparent site index differential of 1.6 m between selection extremes. This was attributed mainly to differences in initial stocking rather than to the effect of selecting taller trees. There was no significant difference ($p>0.05$) in mean diameter at breast height (dbh) due to selection ratio. The straightness of both the unpruned logs and the pruned butts was enhanced with increasing selection. By increasing selection ratio, total merchantable volume and pruned volume were substantially improved, owing to height differences and reduced malformation.

Because of improved quantity and quality, there was an increase in stumpage value at age 19 with increasing selection ratio, the highest selection ratio tested (6:1) being worth $4,000 (29%) more at age 19 than planting at final stockings. This difference is expected to increase to $5,900 (23% more) at age 25 and $8,200 (24% more) at age 30. GF3 genetic stock was less valuable (by $3,700/ha, or 21%) at age 19 than GF13 stock at the same 6:1 selection ratio, had a 1.8 cm smaller dbh, 1.3 m lower mean top height, 50 m^3/ha less total volume, and was inferior in straightness. Although pruned volume was 13 m^3/ha less, the difference was not statistically significant. GF13 stock at a selection ratio of 1.1:1.0 was equivalent in stumpage value to GF3 stock at a 6:1 selection ratio.

At age 25, GF13 is expected to be $5,000 (18%) more valuable, and $5,800 (16%) more valuable at age 30, but this could be an under-estimate because there is some doubt as to the reliability of model projections for new breeds.

Keywords: tree selection; selection ratio; initial stocking; MARVL; Growth and Form Breed; *Pinus radiata.*

INTRODUCTION

A trial was established in 1970 at Cpt 123, Rotoehu Forest, (James 1979) to examine the effects of variation in initial stocking, and thus of selection ratio, using genetically improved material. To this end, 0.2-ha plots were planted using selection ratios of 1:1, 2:1, 3:1, 4:1, 5:1, and 6:1. All higher-stocking plots were thinned to 750 stems/ha in 1975, and to 500 stems/ha in 1976. The final stocking in all plots was 250 stems/ha by 1977. Subsequently there was some mortality in three of the plots. Trees were pruned to 5.9 m. There were two replicates of each treatment, assigned in a random design. For a comparison, two replicates of unimproved (GF3) genetic stock were planted at the 6:1 ratio, and two replicates of field-collected cutting material (from unimproved stock) at the 3:1 ratio (the comparison with cuttings is not described in this report).

Planting Stock

Genetically improved stock

This was an early '850' series seed collection from Gwavas seed orchard, from 14 clones. The orchard had been in operation for only 10 years, and it can therefore be assumed that much of the pollen would have been from external (i.e., unimproved) sources. An approximate rating would be GF13 (Vincent & Dunstan 1989, 16–17).

"Routine" stock

This was drawn from a 3600-kg seedlot obtained from selected trees felled in advance of harvesting operations throughout a number of compartments in Kaingaroa State Forest. Vincent & Dunstan (1989) estimated such material would have an approximate improvement rating of GF3, but this would vary somewhat with the individual batch of seed.

Previous Studies

James (1979) presented results from a 1977 assessment of tree quality in this trial, and concluded that (for the '850' series collection) "only four to six times the final crop stocking need be established for a direct regime". Regarding genetic quality, he stated that "the quality of the 'routine' crop (planted at 1500 stems/ha) approximates that of crops derived from seed orchard seed but planted at only 500 to 750 stems/ha". He added that early selection was not particularly effective, with the percentage of final-crop trees correctly identified at low and medium pruning being, on average, 55% and 73%.

James "hoped that this trial will refute the earlier claims ... that seed orchard seed are no better (or even that they are worse) than trees from routine sources". It seems that, at the time, many managers expected the advantages of improved genetics to be apparent at a very early age. As a part of this refutation he referred to a statistical difference in diameter growth rate.

His analysis involved the meticulous measurement or assessment of various characteristics of stem quality, but no attempt was made to quantify these in terms of "dollar-value" importance.

The trial was re-assessed in 1987 by S.Moore, M.J. Carson, and C.S. Inglis (unpubl. data). Some of the conclusions of their study differed from those of James (1979). Moore *et al* declared that "ratios of 3:1 or less should be adequate when using trees of '850' (GF13) or '268' (GF16) clonal series seed orchard origin" (cf. ratios of 4:1 to 6:1 for James). Results from other trials, including some established in conjunction with this one, influenced these conclusions. Moore *et al.* stated that "the climbing select seedlot (GF3), although planted at 1500 stems/ha, was inferior to the seed orchard seedlot at all levels of initial stocking except 250 stems/ha" (cf. below 500–750 stems/ha for James).

As in James' earlier study, their analysis was based on estimations of "percentage acceptable stems", rather than volumes of log grades of various qualities, or revenue at harvest.

METHODS

MARVL Assessment

MARVL (Method for the Assessment of Recoverable Volume by Log types—Deadman & Goulding 1978; Manley *et al.* 1987) was used to assess every tree in every plot. This technique classifies each section of a stem according to clearly defined quality codes, and the stem is subsequently "cross-cut" into logs by a computer program, in such a way that single-tree value is maximised. The output is a breakdown of recoverable volume per hectare by log grades, and, if these grades are given a value, a valuation of the stand.

For MARVL to be a precise and effective tool, it is important to assess trees consistently, and to select an appropriate "cutting strategy". In this project, assessment of each tree was obtained by consensus of two experienced MARVL assessors (the senior author and J. Nicholls), and so any bias should apply equally to all treatments.

A cutting strategy defines the required attributes for each log grade (minimum and maximum length, small-end diameter, large-end diameter) and gives each log grade a price. Quality codes are explained in Appendix 1 and the cutting strategies used in this study are given in Appendices 2 and 3. The strategy outlined in Appendix 3 is designed to distinguish the proportion of straight logs in the pruned and unpruned element, although in practice the market may not pay a premium for the minor differences in straightness identified here.

It is not necessary in a MARVL assessment to measure the height of every tree. Sufficient trees are measured to generate a Petterson Height Curve so that heights of unmeasured trees can be estimated satisfactorily from their diameters. For this study there were sufficient reliable data from a recent routine re-measurement.

Simulation for Mature Stands

At the time of data collection, the trees were only 19 years old. As trees in New Zealand are usually harvested at 25–30 years, it would be useful to extrapolate the results. The facility for "growing on" MARVL estimates has not yet been developed for Micro-MARVL, but the methodology can be duplicated (with difficulty) on a spreadsheet. The process involves simulating stand basal area and mean top height growth by use of appropriate models, and assuming that the ratio of individual tree to stand values will stay constant. This assumption is clearly only an approximation, but must suffice pending further research.

In this paper, models used to "grow on" stand basal area and mean top height were Growth Model 22 (Pumice Model 1988), and the compatible Height Model 34 (Dunlop in prep.).

Statistical Analysis

The effect of selection ratio and stock type on the variables in Table 1 was tested using regression analysis on plot means. The logarithm of the selection ratio was used in all regressions, partly because it gave a better fit than a straightforward linear regression, and also because, from first principles, gains in yield due to increasing selection ratio would be expected to flatten out above a certain level.

For the two straightness ratios, logistic regressions were used to ensure that the predicted values would lie between 0 and 1. Logistic regression can readily be performed by the Genstat statistical program (Genstat 1987) which was used for all statistical analysis.

After regressions were fitted to the growth variables, an examination of the residuals (observed minus predicted variables) revealed an obvious fertility trend, with large negative residuals at one end of the trial and positive residuals at the other. Previous workers (Moore, Carson & Inglis unpubl. data) had identified this complication but did not quantify the effects on their results.

It was clearly desirable, therefore, to reduce unexplained variability in the analysis by accounting for this trend. One method consists of refitting the regression using the mean residuals of neighbouring plots as a covariate (Papadakis 1937). Other methods fit a smooth trend. For example, Green *et al.* (1985) fitted a trend in which the degree of smoothing could be adjusted by a smoothing parameter. At one extreme, this method fits a linear trend; at the other, it produces a result similar to the Papadakis method. An examination of the residuals in this trial suggested that a linear trend should give a good result, and it did reduce the residual standard deviation by about 50% for height and for diameter at breast height, and consequently for volume and value also.

The Papadakis method also reduced the residual standard deviation (by about 30%), suggesting that the method of adjusting for the fertility trend was not critical. The results reported in the remainder of this paper were obtained using a linear trend. This involved introducing two variables, representing the X and Y co-ordinates of the trial, into the regression equation.

Computer programs or packages used were: data from the Ministry of Forestry Permanent Sample Plot system, Micro-MARVL version 2.0, Genstat 5, and Excel.

RESULTS AND DISCUSSION

The Selection Process

The criteria used by James (1979) to determine selection were:

(1) Stem straightness;

(2) Vigour, defined in terms of crown class (i.e., dominant, codominant, subdominant and suppressed);

(3) Condition of the leader.

Spacing was not specifically mentioned, although this was clearly important.

Given James' criteria, we would expect that there would be noticeable differences in straightness today between selection ratios, especially in those logs that were formed by 1977 (the trees were approximately 12 m tall in 1977). As can be seen in Ratio A and Ratio B in Table 1, there was a distinct difference in the proportion of straight material, both in the pruned butt logs (pruned height 6 m) and in the unpruned logs (6 m to 34 m).

TABLE 1–Predicted values for different selection ratios

Initial stems/ha	Selection ratio	\$/ha 1989	Total vol. (m^3/ha)	Pruned vol. (m^3/ha)	MTH age 19 (m)	Mean dbh (cm)	Ratio A	Ratio B
250	1	13,500	340	116	32.9	45.1	0.74	0.70
500	2	15,000	362	127	33.5	45.2	0.84	0.80
750	3	15,900	375	134	33.9	45.2	0.89	0.84
1000	4	16,600	384	139	34.1	45.2	0.91	0.87
1250	5	17,000	391	143	34.3	45.3	0.93	0.89
1500	6	17,500	397	146	34.5	45.3	0.94	0.90
Significance		**	**	*	**	N.S.	**	*
r^2		0.59	0.58	0.56	0.91	0.59	0.70	0.59

Explanation of terms:

Selection ratio:	Initial stocking (variable) divided by the final stocking (250 stems/ha throughout).
\$/ha:	Current stumpage value, given the price assumptions and specifications for each log grade in Appendix 2.
Total vol:	The total merchantable volume per hectare, given the assumptions in Appendix 2, and given the assumptions implicit in the volume and taper functions used (Appendix 2).
Pruned vol:	The total volume that is classified as P1 or P2 logs (as in Appendix 2). Some pruned logs did not meet the specifications set for straightness, and were downgraded to pulp.
MTH:	The mean top height (mean height of 100 stems/ha with largest dbh) as estimated from a Petterson Equation derived from data obtained in July 1989
Ratio A:	The ratio of good pruned logs (straight, round, no scars) to total pruned logs, by volume, as determined by the criteria in Appendix 3.
Ratio B:	The ratio of straight unpruned logs to total unpruned logs by volume as in Appendix 3.
Significance	Statistically significant ** at the 1% level, * at the 5% level, N.S. not significant.
r^2:	The coefficient of determination, i.e., the proportion of variance explained by the regression equation. In Ratios A and B a logistic regression was used, and the number represents the proportion of deviance explained.

"Vigour" was the second criterion for selection, and we should therefore expect to find evidence of this in a comparison of measurements taken immediately prior to and immediately after each of the (up to three) thinnings. Unfortunately, the records are not always detailed enough for a clear comparison. The first height and diameter measurements were taken immediately after the first thinning (May 1975) and height was not recorded again until 1980, 2 years after the final thinning in August 1977.

There were height differences between selection extremes (1:1 to 6:1) for all years and these differences appeared to be increasing (Table 2).

When mean top height for 1975 was used as a covariate in the analysis of the 1980 data, it proved to be highly significant while the selection ratio effect became non-significant (at the 5% level). Neither the 1975 nor the 1980 data, however, were significant when used as covariates in the analysis of the 1989 mean top height.

Higher selection ratios imply a greater choice at the time of selection, including choice on the basis of height. Because a narrower band of the height distribution is selected with

TABLE 2–Smoothed mean top height differences between selection extremes for 1975, 1980, and 1989

Year	MTH differences (m)
1975	1.04*
1980	1.32*
1989	1.60*

* Statistically significant at the 5% level

higher selection ratios, one would expect the remaining trees to be taller. Nevertheless, it may not be correct to infer that the original 1.04 m height difference was caused by selecting taller trees in the first selection, and that the increase to 1.32 m by 1980 was caused by the second selection. Other possibilities include:

(a) Stocking/height growth interaction. Higher selection ratios have higher stockings for the first few years and this may "force up" height growth (J.P. Maclaren, unpubl. data).

(b) Delayed selection effect. Final selections were delayed in the higher selection ratios, enabling the selector to reject trees that did not perform according to their early promise.

In fact, it is possible to calculate that the increase in height due to the first selection would have been only 0.45 m (West *et al.*1987). In any event, the height differences recorded at the time of final selection have persisted, and have even increased. The existing 1.6 m difference between extremes has a marked influence on calculated volume per hectare.

The situation with diameter is somewhat confused. There was no statistically significant difference in 1977 diameter (i.e., after the final thinning) with selection ratio (Table 3), and the observed difference between mean diameters of selection extremes was less than 2 mm. This lack of difference has persisted unchanged.

TABLE 3–Smoothed mean diameter at breast height measurements for 1977

Selection ratio	Dbh 1977
1:1	19.3
2:1	19.3
3:1	19.4
4:1	19.4
5:1	19.4
6:1	19.4
R (6:1)	18.6 N.S.

Neither the trend in diameter increase with selection ratio, nor the difference due to genetic stock, was statistically significant.

This homogeneity of diameter after final selection does not imply that no selection took place on the basis of diameter, as mean diameters were initially lower in the plots where greater selection was practised. In other words, the selection effect nearly counteracted the suppression effect that occurred through higher initial stockings—there was, in fact, a mean increase in mean diameter of 0.5 cm due to the second selection (750 stems/ha reduced to 500 stems/ha), and a mean increase of 1.5 cm due to the third selection (500 stems/ha reduced to 250 stems/ha).

Effect of Seedlot

At the final thinning, GF13 stock was taller and of greater diameter than GF3 stock, although the differences were not statistically significant ($p>0.05$). The disparity has increased over the intervening period and now there is a statistically significant ($p<0.05$) difference (Table 4) (although the differences are not detectable until an adjustment is made for the trend in fertility across the trial). Diameter at breast height of GF13 stock has increased by 0.93 cm between 1977 and 1989 relative to GF3 stock.

TABLE 4–Comparison of GF13 and GF3 seedlings, at a 6:1 selection ratio

Stock	$/ha	Total vol. (m^3/ha)	Pruned vol. (m^3/ha)	MTH (m)	Mean dbh (cm)	Ratio A	Ratio B
GF3	13,800	347	133	33.2	43.5	0.74	0.73
GF13	17,500	397	146	34.5	45.3	0.94	0.90
Difference	3,700**	50**	13N.S.	1.3**	1.8*	**	*

N.S. Not statistically significant
* Significant at the 5% level
** Significant at the 1% level

Similarly, the difference in mean top height over the 12 years since final thinning has increased by at least half a metre, and probably by over 1 m (uncertainty exists because height in 1977 must be interpolated).

The most-pronounced characteristic of GF13 stock is the improvement in straightness. This is not surprising in view of Thulin's statement (1969) that, in choosing the orchard material, there was "a high selection intensity for stem straightness, branching and absence of stem cones in the lower 18 m of the bole and a relatively low selection intensity for vigour". The proportion of straight volume in GF3 stock was 0.74 (pruned butts) and 0.73 (unpruned) (Table 1). This is a sharp contrast to the GF13 stock with equivalent treatment, which provided figures of 0.94 and 0.90.

There can be no hesitation, therefore, in endorsing James' early finding that GF13 genetic stock is decidedly superior to GF3 stock. Moreover, this difference has arisen not just during early growth; if anything, it increases with age. Pederick & Eldridge (1983), in an unrelated study, supported this conclusion.

In terms of value, it appears that the selection ratio required for GF13 stock in order to make it equivalent to a 6:1 selection for GF3 stock is approximately 1.1:1.0, or a selection of 10 trees out of every 11 planted.

Simulation for Mature Stands

Height, volume, and pruned volume differences due to selection ratio are predicted to continue to diverge (Table 5), but not diameter differences, which reverse the (non-significant) trend apparent at age 19. The reason for this is that the stocking is slightly lower in the two 1:1 selection ratio plots, and a diameter response is predicted as a result of lower stockings.

Some mortality is seen as inevitable in any "plant at final stocking" regime, because there is no opportunity to replace crop trees from the ranks of the culls. For this reason, no attempt

TABLE 5–Predicted values for stands aged 25 and 30

	Age 25				Age 30			
Selection ratio	MTH (m)	Dbh (cm)	Total vol. (m^3/ha)	Pruned vol. (m^3/ha)	MTH (m)	Dbh (cm)	Total vol. (m^3/ha)	Pruned vol. (m^3/ha)
1	40.6	52.2	570	167	45.6	55.8	712	195
2	41.3	51.9	601	182	46.3	55.5	751	215
3	41.7	51.8	619	191	46.7	55.3	775	227
4	41.9	51.6	632	198	47.0	55.2	790	236
5	42.1	51.5	642	202	47.2	55.1	804	242
6	42.3	51.4	650	207	47.4	55.0	814	247
6 (GF3)	41.1	50.3	593	190	46.2	54.1	753	223

has been made to calculate the situation as if there were no mortality. (In the 1:1 selection ratio five trees out of 50 died in one plot, and two out of 50 in the other. The only other mortality recorded was one tree in a 3:1 ratio plot.)

Volume and pruned volume differences due to tree breed continue to increase slightly, in spite of the height differences remaining constant and the diameter difference decreasing. This "convergence" of height and diameter is a feature of the growth model used (PPM88), and it is not yet known whether this mimics reality (Dunlop *et al.*, in prep.). Because of the convergence effect of many modern growth models, Carson (1988) did not use them for his financial analysis of the value of new breeds.

Economic Considerations

It is patently more expensive to grow stands with higher selection ratios, even if these high initial stockings yield a greater revenue at harvest. A comparison of the costs and benefits of selection ratio could be informative although interpretation will depend on assumed:

- silvicultural costs;
- rate of time preference (discount or compound interest rate);
- premium for straightness;
- rotation length.

For this exercise, the regimes used were those actually implemented in the trial although cheaper regimes are now standard practice. Costs for these operations were derived from the data of Lewis (1986) and not adjusted for inflation as the revenues were also derived for 1986. Compound interest rates of 5%, 8%, and 10% were assumed in order to straddle the range of rates likely to be used. No premium for straightness was assumed. Provided that logs met with the log-grade specifications in Appendix 2, their mean straightness was taken to make no difference in price. Moreover, it must be appreciated that MARVL is an assessment of the external characteristics of trees and pith deviation is likely to become hidden over time. James (1979) detected very great differences in stem straightness with selection ratio. For example, in the 1:1 selection ratio treatment only 29% of trees were recorded as straight (*versus* about 70% for this study). The handling of sweep in this exercise, therefore, tends to work in favour of the lower selection ratios.

Rotation length was assumed to be 19 years but since, in practice, few silviculturalists advocate harvesting at this young age even if mean dbh is acceptable, estimates are also given for ages 25 and 30 (Table 6). Cost assumptions (Appendix 4b) include only those costs that can be expected to vary with selection ratio, because fixed costs vary widely with the situation and do not affect the comparison.

TABLE 6–Cost/benefit analysis of selection ratio for 19-, 25-, and 30-year-old trees at 5%, 8%, and 10% compound rates

	Selection ratio					
	1	2	3	4	5	6
Revenue ($)*						
Age 19	13,500	13,100	16,000	16,600	17,100	17,500
Age 25	26,100	28,300	29,700	30,600	31,400	32,000
Age 30	33,800	37,000	38,800	40,200	41,200	42,000
Compound costs ($)						
@ 5%						
Age 19	1,020	1,820	2,510	2,820	3,090	3,360
Age 25	1,370	2,440	3,360	3,780	4,130	4,500
Age 30	1,750	3,110	4,290	4,820	5,280	5,750
@ 8%						
Age 19	1,530	2,740	3,800	4,310	4,740	5,190
Age 25	2,430	4,350	6,080	6,840	7,530	8,240
Age 30	3,570	6,390	8,870	10,050	11,060	12,110
@ 10%						
Age 19	2,010	3,600	5,000	5,700	6,300	6,290
Age 25	3,550	6,370	8,870	10,100	11,160	12,260
Age 30	5,720	10,260	14,280	16,260	17,970	19,740
Net benefit ($)						
@ 5%						
Age 19	12,500	13,300	13,500	13,800	14,000	14,100
Age 25	24,700	25,900	26,300	26,800	27,300	27,500
Age 30	32,100	33,900	34,500	35,400	35,900	36,300
@ 8%						
Age 19	12,000	12,300	12,200	12,300	12,400	12,300
Age 25	23,700	24,000	23,700	23,800	27,300	23,800
Age 30	30,200	30,600	30,000	30,200	30,100	29,100
@ 10%						
Age 19	11,500	11,500	11,000	10,900	10,800	10,600
Age 25	22,500	21,900	20,800	20,500	20,200	19,700
Age 30	28,100	26,700	24,500	23,900	23,200	21,500

* Stumpage values at ages 19, 25, and 30 years

Two results are immediately apparent: firstly, there is a trade-off between the costs and benefits of selection ratio, so that there is no great difference in the end result. Secondly, choice of interest rate will affect the conclusions drawn. At a 10% compound rate, silvicultural costs adopt a greater importance and therefore lower selection ratios are favoured, and vice versa for the 5% rate.

The silvicultural cost assumptions used here may well be inappropriate for some managers. It may therefore be useful to examine the sensitivity of "optimum" selection ratio to varying silvicultural costs. At the 5% discount rate, costs would have to be increased by 69% for the trend to be reversed. At the 10% rate, costs would have to be reduced by 20%.

At 8% compound interest there is no clear trend in the revenues less discounted costs, because the costs were derived from regressions based on workstudy data that were not always harmonised. In addition, the stepped thinning regimes used would create some "lumpiness". We can say, though, that at the 8% discount rate, and at the costs assumed here, selection ratio appears to be of trivial importance.

The equivalent revenues for GF3 stock (6:1 selection ratio) at ages 25 and 30 were calculated to be $27,000 and $36,100 respectively.

In practice, selection ratio would also be based on factors outside the scope of this analysis. For example:

Risk: If selection ratios are low, there is a greater chance of a given percentage mortality resulting in under-utilised land.

Availability of tree stock: There may be a restriction on supplies of good genetic tree stock, the benefits of which exceed the price differential over inferior stock. In that situation it may pay to plant lower initial stockings.

Cash flow: A manager may choose to adopt lower initial stockings in order to overcome cashflow bottlenecks, even if this solution is suboptimal in terms of stand profitability.

CONCLUSION

Selection Ratio

Increasing selection ratio of improved tree stock in this trial produced a taller and straighter crop, although diameter was unaffected. This resulted in a $4,000 increase in value at age 19, rising to an estimated $5,900 difference at age 25 and $8,200 difference at age 30. The increase in value through greater selection was offset by an increase in silvicultural costs associated with greater numbers of trees that required planting, pruning, and thinning.

The initial stocking that yields the greatest profit, however measured, will depend on the type of regime chosen, on precise figures for silvicultural costs, and on choice of discount (compound) interest rate. It is therefore not possible to make firm pronouncements on a "rule-of-thumb" optimum selection ratio.

In any case, it appears that selection ratio is not a critical silvicultural issue. The differences in crop values resulting from selection are minor given the differences that stem from other factors, such as risk of poor establishment, poor form due to early wind or animal damage, or cash-flow constraints. Choice of selection ratio would, and perhaps should, be made on the basis of criteria not applicable to the single hectare (individual stand) situation.

Genetic Improvement

Even though the GF13 stock used in this trial represents an orchard product arising from an early stage in the breeding programme, it is quite clear that it is capable of producing substantially better stands than stock from unimproved "felling select" seed, at least on the Rotoehu site. GF13 was superior in diameter, height, and straightness, and generated a $3,700/ha improvement in value (at age 19) for a small difference in cost. This rises to $5,000 difference at age 25, and $5,800 difference at age 30.

A selection ratio of 6:1 for GF3 stock (felling select) appears to be equivalent in stumpage value at age 19 to a ratio of 1.1:1.0 for GF13 stock—the latter ratio is the same as planting 11 trees for every 10 that are required for the final crop.

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APPENDIX 1

STANDARD DICTIONARY OF QUALITY CODES

(from Manley *et al.*1987, p. 3)

Code	Quality
A	Pruned, straight, peeler quality
B	Pruned, straight, not peeler quality
C	Pruned, mod. sweep, peeler quality
D	Pruned, mod. sweep, not peeler quality
E	Unpruned, branches <6 cm, straight, not peeler
N	Unpruned, branches <6 cm, straight, peeler
G	Unpruned, branches <6 cm, mod. sweep
L	Unpruned, branches 6–14 cm, straight
K	Unpruned, branches 6–14 cm, mod. sweep
I	Internodal, branches <6 cm, straight
J	Internodal, branches 6–14 cm, straight
P	Pulp
W	Waste

Notes:

(1) A log is not a peeler if two diameter measurements (measured with calipers) differ by more than 10%, if there is severe fluting, or if there is any bark damage. Note that a number of logs classified as "peeler" from external features will be downgraded on felling as a result of pith displacement.

(2) Internodal logs have more than 60% of their length in straight internodes 60 cm or greater.

(3) There are four sweep classes (Gosnell 1987), expressed here as a proportion of small-end diameter. Sweep Class 4 is waste, Class 3 is pulp, Class 2 is "moderately swept" (as above), and Class 1 is "straight".

Class	For 5.5 m log	For <3.7 m log
1	<D/8	<D/16
2	D/8–D/4	D/16–D/8
3	D/4–D/2	D/8–D4
4	>D2	>D4

(4) Logs can be downgraded to pulp for displaying one or more of the following types of defects: sweep Class 3, a branch greater than 14 cm, or bark damage likely to indicate sapstain fungus.

APPENDIX 2

A "REALISTIC" CUTTING STRATEGY

(stumpages supplied by B.R. Manley, Forest Research Institute)

Log grade (length m)	Min. s.e.d. (cm)	Max. s.e.d. (cm)	Max. l.e.d.* (cm)	Value ($/m^3)	Log qualities
P1 (2.7–5.7)	40	150	150	86	ABCD
P2 (2.7–5.7)	30	40	150	58	ABCD
S1 (5.5–5.5)	40	150	150	55	ABCDINEG
S2 (5.5–5.5)	30	40	150	40	ABCDINEG
S3 (3.1–6.1)	20	30	150	16	ABCDINEG
S4 (3.1–6.1)	15	20	150	12	ABCDINEG
L1 (5.5–5.5)	40	150	150	47	ABCDINEGJLK
L2 (5.5–5.5)	30	40	150	32	ABCDINEGJLK
L3 (3.1–6.1)	20	30	150	7	ABCDINEGJLK
L4 (3.1–6.1)	15	20	150	6	ABCDINEGJLK
Pulp (1.2–6.1)	10	150	150	5	ABCDINEGJLKP
Internodal (3.7–6.1)	30	150	150	56	ABCDIJ
Waste (0.0–20.0)	0	150	150	0	ABCDINEGJLKPW

Stump height: 0.3 m
Round-off length: 0.1 m
Cost per sawcut: $0.50
Functions used were: volume V16; taper T16; breakage B16 (Micro-MARVL User Guide, version 2.1)

* s.e.d. = small-end diameter of log.
l.e.d. = large-end diameter.

APPENDIX 3

A CUTTING STRATEGY TO IDENTIFY PROPORTION OF SWEPT LOGS
(stumpages adjusted from B.R. Manley, Forest Research Institute)

Log grade* (length m)	Min. s.e.d. (cm)	Max. s.e.d. (cm)	Max. l.e.d. (cm)	Value ($/m^3)	Log qualities
Good pruned (2.7–5.7)	30	150	150	86	A
Poor pruned (2.7–5.7)	30	150	150	58	ABCD
Straight (3.1–5.5)	25	150	150	55	ABINEL
Crooked (5.5–5.5)	25	150	150	40	ABIJNEGLK
Pulp (1.2–6.1)	5	150	150	5	ABIJNEGLKP

Stump height:	0.3 m
Round-off length:	0.1 m
Cost per sawcut:	$0.50

* "Good pruned"	This category excludes logs with moderate sweep (*see* Appendix 1 for definition).
"Poor pruned"	These can have moderate sweep, but neither type of pruned log may have severe sweep, excessive fluting, ovality or bark damage (*see* Appendix 1). The ratio of Good Pruned to (Good + Poor Pruned) is Ratio A in Tables 1 and 4.
"Straight"	Unpruned logs of branch size up to 14 cm, but excluding logs of moderate sweep.
"Crooked"	Unpruned logs of branch size up to 14 cm, but can include logs of moderate sweep. Neither type of unpruned log can have branches in excess of 14 cm or severe sweep. The ratio of Straight to (Straight + Crooked) is ratio B in Tables 1 and 4.

APPENDIX 4a

SILVICULTURAL REGIMES USED FOR THE TRIAL

Numbers of trees per hectare planted, pruned, and thinned (residual stocking)

Selection ratio	Year 0 Trees planted	Year 5		Year 6		Year 7	
		Pruned 1	Thinned 1	Pruned 2	Thinned 2	Pruned 3	Thinned 3
1	250	250	-	250	-	250	-
2	500	500	-	500	-	250	250
3	750	750	-	500	500	250	250
4	1000	750	750	500	500	250	250
5	1250	750	750	500	500	250	250
6	1500	750	750	500	500	250	250

APPENDIX 4b

COSTS OF EACH OPERATION ($)

1986 values, interpolated from Lewis (1986)

Selection ratio	Year 0		Year 5		Year 6		Year 7	
	Stock	Planting	Pruning 1	Thinning 1	Pruning 2	Thinning 2	Pruning 3	Thinning 3
1	33	60	135	–	135	–	147	–
2	65	109	251	–	251	–	147	80
3	98	152	440	–	251	66	147	80
4	130	194	440	63	251	66	147	80
5	163	232	440	107	251	66	147	80
6	195	275	440	150	251	66	147	80

The costs in Year 0 consist of tree stocks, planting costs, and spot spraying costs. The latter two are combined in the table.