TIMBER RECOVERY FROM PRUNED PINUS RADIATA BUTT LOGS AT MANGATU: EFFECT OF LOG SWEEP

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ABSTRACT

Sixty 5.5-m pruned butt logs, from two managed stands of **Pinus radiata** D. Don in Mangatu State Forest, were selected on the basis of three size classes and three sweep categories. All logs were sawn to 25-mm boards using a standard conversion procedure in a single-band sawmill at Rotorua. The produce was graded according to commercial grades and provisional Clear and Clear-cutting grade classifications.

Conversion factors increased with increasing log size and decreased with increasing sweep. A change in the sweep : diameter ratio (deviation : small-end diameter (s.e.d.)) of 0.1 was associated with an average drop in timber recovery of about 5%. Straight logs (average s.e.d. = 390 mm) yielded 45% of the outturn in Clear grades compared to 34% and 28% for moderately swept (average sweep 16 mm/m) and severely swept (30 mm/m) logs respectively. Increasing sweep also caused a marked reduction in the recovery of Clearcuttings longer than 3 m.

Regression equations linking log characteristics and grade outturn indicated that only the higher grades can be predicted on an individual log basis with any degree of confidence. The most significant log variables were small-end diameter, defect core diameter, sweep, and taper.

INTRODUCTION

Log straightness has long been recognised as an important quality characteristic and has featured prominently in log grading rules (e.g., Schroeder *et al.* 1968) and tree breeding programmes worldwide. However, despite advances in the mass production of genetically improved trees and intensive silvicultural operations which reduce the numbers of malformed stems in *Pinus radiata* plantations, a proportion of the final-crop trees inevitably contains stem curvature (sweep). This may be due to environmental, genetic, or pathogenic influences. In extreme examples unstable ground conditions may cause the entire tree to change position, and subsequent growth patterns may induce sweep.

While the presence of sweep is widely recognised, few studies have been reported which tackle the economic impact of the phenomenon. Dobie (1964), MacDonald & Sutton (1970), and Williston (1981) documented substantial losses, particularly with small swept logs. Pieces from the outside of swept logs are more likely to require edging or trimming to remove wane. Hence, losses are proportionately higher in small logs and pruned logs with a narrow clearwood sheath. Dobie (1964) compared yield and quality of *Pseudotsuga menziesii* (Mirb.) Franco timber from straight and swept logs (350 mm s.e.d.). On average, swept logs gave 15% less timber, with a greater proportion of lower grades. There was also a positive association between the degree of log sweep and the sawing time required to produce a given volume of timber. Swept logs took almost 40% more time at the circular headrig used in the study.

In a later study, Dobie & Middleton (1980) assessed lumber yields from swept *Pinus contorta* Loud. logs at two sawmills in British Columbia, and derived a general rule of thumb that each 0.1 increase in the sweep : diameter ratio (maximum deviation : s.e.d.) gives a yield reduction of about 7% compared to straight logs.

Another study of *P. contorta* in Ireland indicated that recovery losses of the order of 30% could be expected in swept logs averaging 280 mm d.b.h. (Fitzsimmons 1982). However, it was concluded that it would not be profitable to sacrifice vigour for slower growing but straighter crops.

In a study of 400 unpruned *P. radiata* logs in Australia, Brown & Miller (1975) found diameter and sweep to have a strong impact on conversion when the sweep : diameter ratio exceeded 0.15 in logs averaging 330 mm d.b.h. However, at best only 45% of the variation in conversion could be explained using log parameters. On average, swept logs (mean sweep 13 mm/m) yielded 20% less sawn output.

Whiteside (1982a) noted that sweep decreased the conversion and value of timber of *P .radiata* cut to framing sizes. However, the great majority of pruned butt logs sawn experimentally in New Zealand have been nominally straight (Fenton *et al.* 1971; Vaney 1981; Park & Parker 1983).

Problems with production rates and product values have resulted in attempts by some Scandinavian and North American sawmills to compensate for log sweep by sawing parallel to the bark or the pith in sash gang-saws. Such systems for "sawing around the curve" have been claimed to improve timber yield of small logs by up to 4% (Williston 1976).

The effect of log sweep on the sawing process and timber value is of wide interest as it has a bearing on:

(1) Grade outturn from stands with varying degrees of log sweep;

(2) Suitability of sweep limitations in log grade specifications;

(3) Advisability of pruning swept logs;

(4) Potential benefits from sweep sawing;

(5) Potential benefits from further genetic manipulation of stem form;

(6) Selection criteria used in thinning prescriptions.

MATERIALS AND METHODS

As part of a continuing series of sawmill studies, samples of pruned butt logs were obtained from two compartments in Mangatu State Forest. This particular forest was selected because the reputedly high-than-normal incidence of stem sweep is attributed to the unstable soil conditions and may be characteristic of logs from this region. The two sample stands are representative of one type of managed crop scheduled to be harvested from 1985 onwards in this area (Table 1).

TABLE 1—Stand histories

Operation	Cpt 1	Cpt 36
Planted	1960 - 2300 stems/ha	1962 - 1980 stems/ha
Low pruning (2.4 m)	1964–65 - 1112 stems/ha	1967 - 1980 stems/ha
High pruning (5.5 m)	1968 - 544 stems/ha	1970 - 220 stems/ha
Thinning	1968 to 544 stems/ha	1970 to 220 stems/ha

As a preliminary assessment of butt log characteristics, samples of 200 stems were measured in each compartment for breast height diameter (d.b.h.) and stem straightness. The latter was estimated by placing a 6-m aluminium pole against the mid points of each end of the butt log perpendicular to the plane of sweep, and recording the maximum deviation from the central log axis. Each log was assigned a sweep classification based on the relationship between deviation and diameter at that point – i.e., straight (O–D/8), D/8–D/4, D/4–D/3, D/3–D/2, and >D/2. The results of these inventories are shown in Fig. 1.

In these sample compartments, 45% of the butt logs were straight, 35% slightly swept, and 20% showed pronounced sweep (deviation >D/4).

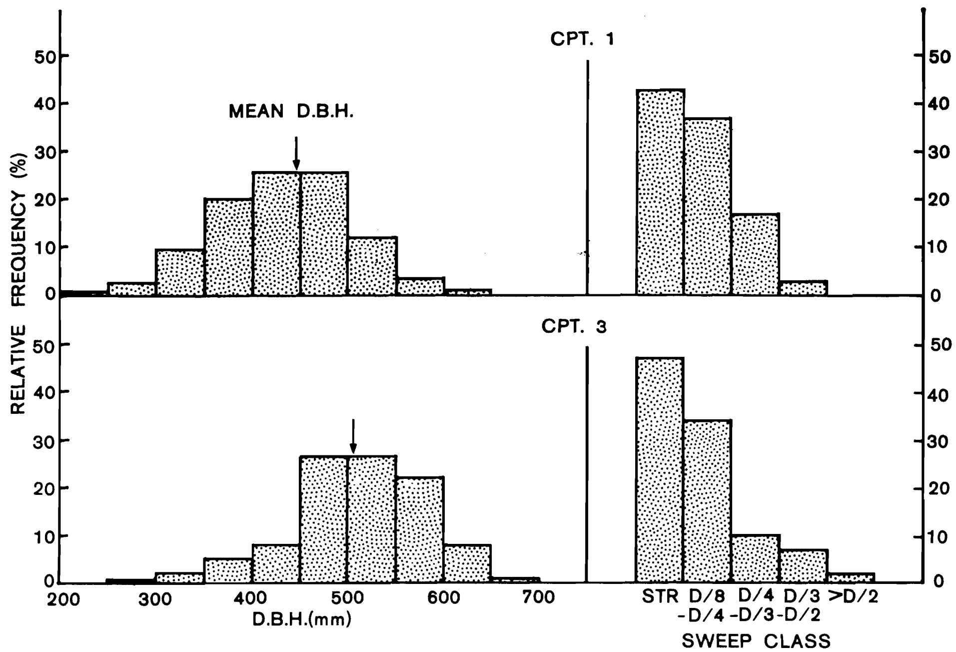


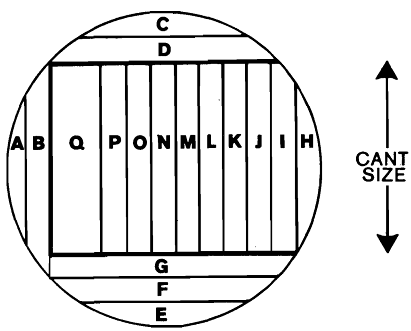
FIG. 1—Relative frequency distributions for d.b.h. and sweep classes.

Since the effects of log size and sweep are interactive, a two-way sampling strategy was adopted for each compartment to ensure adequate coverage of the log characteristics (Table 2). It should be emphasised that the sampling objective was not to obtain "representative" logs from each area but rather to cover the range of log types in such a way that predictive models could best be derived – hence the preponderance of samples at the extremes of the characteristics assessed (size and sweep) rather than around the average values. Sample logs were selected from those inventoried, on the basis of the measured d.b.h. and visual sweep class, i.e., straight, moderately swept (deviation D/4–D/3), and severely swept (deviation D/3 or more).

TABLE 2—Log sample numbers

Sweep class	Log size class (s.e.d. - mm)		
	250–350	351–450	451+
Straight	4	3	4
Moderate	3	2	3
Severe	4	3	4

Sixty 5.5-m pruned butt logs were delivered to the Timber Industry Training Centre sawmill at Rotorua, and their external characteristics were measured according to standard procedures (Park & Leman 1983). Primary breakdown was accomplished on the single-band headrig using the saw pattern shown in Fig. 2. Cant size was determined during cutting and was dependent on the size of the defect core. Clearwood recovery from the board flitches was optimised at the multi-saw edger. Green target size was 25 mm (zero overcut) and the minimum length recovered was 1.8 m.



BOARD FLITCHES CUT TO 25mm, EXCEPT "Q" WHICH WAS CONVERTED TO TWO 25mm BOARDS AT THE RESAW

A,C,E,H, - TO BREAST BENCH

B,D,F,G, - TO MULTI-SAW EDGER

FIG. 2—Headrig saw pattern.

With swept logs, carriage design did not permit positioning in the "horns down" fashion, so the bedding cuts (A and B in Fig. 2) removed some of the sweep on the concave sides of the logs.

In the timber yard all logs were reconstructed using sawing diagrams, and details of the defect cores were recorded in two directions as described by Park & Leman (1983), i.e., A–H and C–E in Fig. 2.

All timber was graded according to NZS 3631 : 1978 (National Timber Grading Rules) except that the provisional clear grades (No. 1 Clear, No. 2 Clear, and No. 1 Cuttings grades – Whiteside 1982b) were included and Finishing and Dressing grades omitted. Clearcuttings were recorded in increments of 100 mm with a minimum length of 300 mm. Both timber grades and clearcuttings were assessed (a) including the influence of resin pockets, and (b) ignoring resin pockets. This is because the incidence of this defect is both highly variable between trees and strongly influenced by geographic location (Cown 1973). In some studies their occurrence can be an additional confounding factor. Unless otherwise stated, timber grades and clearcuttings are expressed in this report ignoring resin pockets.

The defect cores were defined as by Park (1980), i.e., a cylinder containing pith, branches, and occlusion scars. The diameter was assessed from the defect measurements in the two directions, with the proviso that the core diameter in the plane of maximum sweep could not exceed the small-end diameter of the log.

Results were analysed using the procedure outlined by Park & Leman (1983) and the timber output was valued according to Price List B of Whiteside (1982a). This is based on a fixed price of $100/m^3 for 100 $\times$ 50-mm No. 1 Framing and 100 $\times$ 25-mm Dressing grades, and includes differentials for other grades based on the North Island Price List and premiums for the provisional clear and clearcuttings grades calculated from export prices.

Regression analyses were undertaken to derive relationships between timber grades and values and log parameters.

RESULTS

A summary of log characteristics by compartments and sweep classes is given in Table 3. The two sets of log samples were very similar as regards both external and internal characteristics. Grade Indices are given to enable comparison with previous studies on pruned logs using a similar sawing pattern (Park 1980; Park & Parker 1983).

Timber Recovery

The effect of log sweep on conversion was marked in both sample sets (Table 4). An analysis of individual logs (Fig. 3) revealed a consistent downgrading influence across the range sampled, attributable to sweep. Conversion factors averaged 57.9%, 52.0%, and 46.1% for the straight, moderately swept, and severely swept logs, respectively. This means that the moderately swept logs (sweep average 16 mm/m) yielded 10% less timber than the straight logs and the severely swept gave 20% less. However, the interaction of log size and sweep is apparent in Fig. 3 where it can be seen that on average a 50% conversion was achieved with straight logs of 280 mm

TABLE 3—Log data

	Cpt 1			Cpt 36		
	Straight	Moderate sweep	Severe sweep	Straight	Moderate sweep	Severe sweep
Number of logs	12	7	10	12	10	9
d.b.h. (mm)	475	513	500	497	516	492
s.e.d. i.b. (mm)	376	404	385	409	408	389
Sweep (mm/m)	6.2	15.7	27.9	6.0	16.4	32.4
Taper (mm/m)	13.3	15.8	15.3	15.5	18.2	18.3
Defect core (mm)	290	328	333	301	333	340
Grade index*	0.96	0.82	0.71	0.94	0.81	0.64

* Park (1980) - Grade index $= \dfrac{\text{d.b.h.} \times \text{conversion}}{\text{defect core}}$

s.e.d., moderately swept logs of 360 mm s.e.d., and severely swept logs of 500 mm s.e.d. The precision of the relationships as indicated by the r^2 values is not high, and confirms the findings of Kerbes & McIntosh (1968), Grant (1977), and others, who have shown a considerable amount of variability in the conversions realised from individual logs.

The timber recovery losses attributable to sweep average about 5% for each 0.1 increase in the sweep : diameter ratio – somewhat less than the 7% quoted by Dobie & Middleton (1980) for *P. contorta.*

TABLE 4 — Log and timber volumes

	Cpt 1			Cpt 36		
	Straight	Moderate sweep	Severe sweep	Straight	Moderate sweep	Severe sweep
Number of logs	12	7	10	12	10	9
Round volume (m^3)	9.2381	6.2886	8.0923	11.2191	8.2892	7.6139
Timber volume (m^3)	5.4211	3.3072	3.8557	6.4194	4.3179	3.3900
Conversion (%)	58.7	52.6	47.6	57.2	52.1	44.5

Grade Recovery

Some differences in green grade recoveries are apparent (Table 5), particularly in the amount of No. 1 Clears obtained from the two compartments, but over-all the grade proportions are fairly similar, bearing in mind the relatively small number of logs and the high degree of individual log variation. As the main objective of the study was to quantify the effect of sweep, the samples from the two locations were combined to increase the numbers in an over-all size/sweep class comparison (Table 6, Fig. 4 and 5).

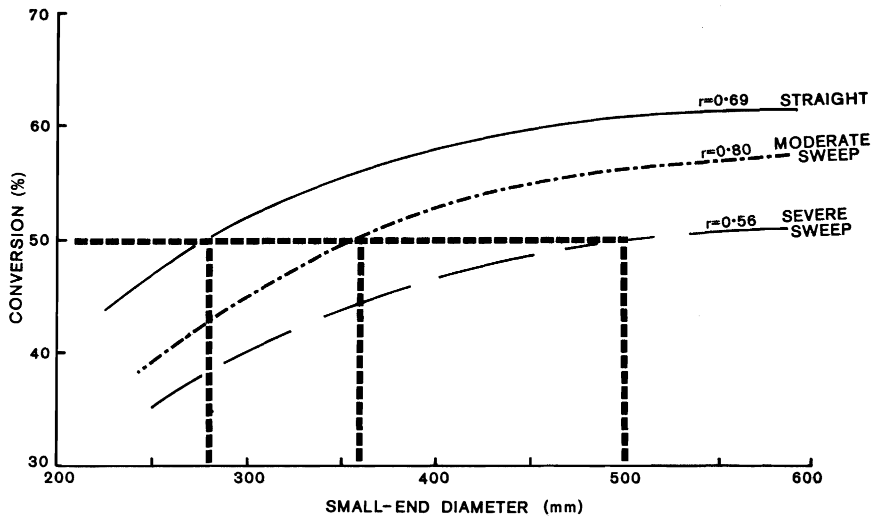


FIG. 3—Relationships between log size, sweep, and conversion percentage.

TABLE 5—Grade recoveries (% sawn volume) by compartment and sweep class

Grade	Cpt 1			Cpt 36		
	Straight	Moderate sweep	Severe sweep	Straight	Moderate sweep	Severe sweep
No. 1 Clear	29.0	19.1	24.6	38.8	31.9	19.2
No. 2 Clear	12.5	9.4	10.2	13.3	10.4	6.1
No. 1 Cuttings	11.6	15.5	3.6	8.2	9.3	3.5
Factory	12.7	16.9	19.5	11.8	10.4	24.1
Merchantable	28.7	26.7	32.9	14.7	25.5	30.8
Box	5.5	12.4	9.2	13.2	12.5	16.3
Total	100.0	100.0	100.0	100.0	100.0	100.0
Conversion (%)	58.7	52.6	47.6	57.2	52.1	44.5

Straight logs yielded 45% of the outturn in the provisional clear grades (No. 1 and No. 2 Clears), compared to 34% for moderately swept logs and 28% for severely swept logs. Cuttings grades (No. 1 Cuttings and Factory) increased with increasing stem sweep from an average of 20% to 27%. The "other boards" category shown in Fig. 4 (Merchantable and Box grades combined) increased steadily through the sweep classes from 35% to 46%.

Differences in grade percentages between the medium and large logs were small in comparison to the differences between the small logs and the others.

The recovery of provisional clear grades from straight logs was substantially higher than reported by Vaney (1981) for samples from one of the study areas (41.5% of sawn timber *v.* 25.4%). This can be attributed to (a) the larger average s.e.d. (376 mm *v.* 333 mm) relative to the defect core diameter (290 mm *v.* 295 mm), and (b) the

TABLE 6—Grade recoveries by log size and sweep classes

Sweep class	Timber grade	Grade recoveries (% sawn volume) Log size class (s.e.d. - mm) 250–350	351–450	451+	Arithmetic means
Straight	No. 1 Clear	15.8	37.7	38.5	30.7
	No. 2 Clear	14.7	16.3	10.4	13.8
	No. 1 Cuttings	4.9	7.2	12.8	8.3
	Factory	14.4	6.7	14.6	11.9
	Merchantable	35.1	27.7	12.8	25.2
	Box	15.1	4.4	10.9	10.1
	Total	100.00	100.0	100.0	100.0
	Conversion (%)	51.3	59.8	59.3	
Moderate sweep	No. 1 Clear	13.0	33.4	27.9	24.8
	No. 2 Clear	8.0	10.3	10.4	9.6
	No. 1 Cuttings	4.2	15.3	11.9	10.5
	Factory	16.2	10.2	13.8	13.4
	Merchantable	51.1	19.1	21.9	30.7
	Box	7.5	11.7	14.1	11.0
	Total	100.00	100.0	100.0	100.0
	Conversion (%)	45.2	51.4	54.5	
Severe sweep	No. 1 Clear	9.3	26.4	24.0	19.9
	No. 2 Clear	6.2	8.8	8.8	7.9
	No. 1 Cuttings	4.1	4.9	2.0	3.7
	Factory	33.9	17.9	19.5	23.8
	Merchantable	31.7	35.7	29.7	32.4
	Box	14.8	6.3	16.0	12.3
	Total	100.00	100.0	100.0	100.0
	Conversion (%)	42.1	43.1	50.5	

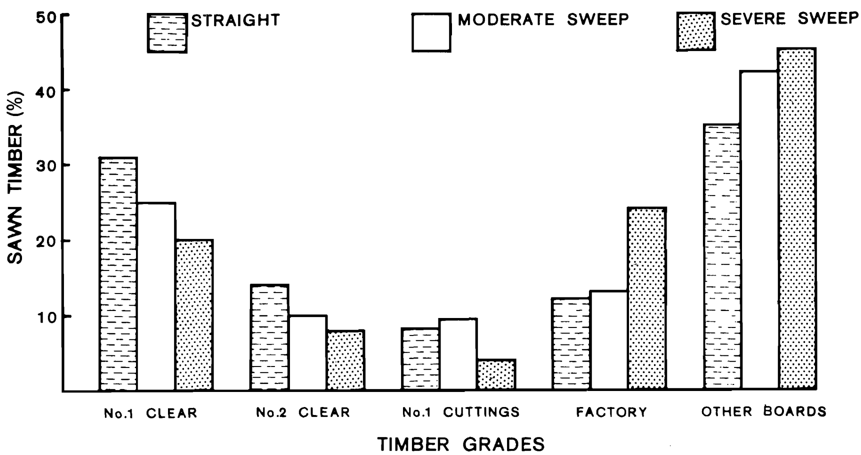


FIG. 4—Effect of log sweep on grade recovery.

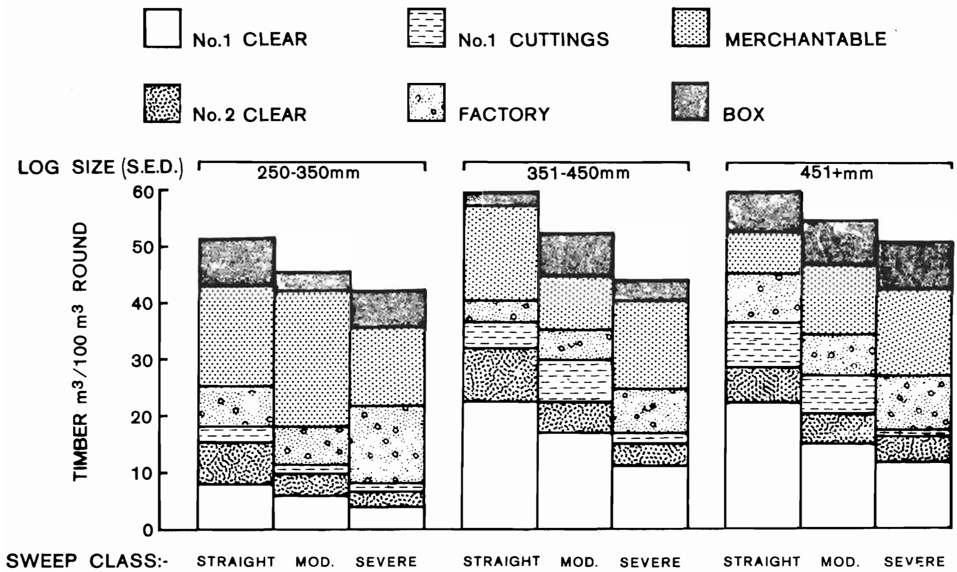


FIG. 5—Effect of log size and sweep on sawn timber recovery

different edging routine adopted (grade ripping *v.* edging for maximum volume). In several overseas studies grade ripping has been shown to increase the value of the sawn output (Pnevmaticos & Bousquet 1972).

Clearcuttings

Log sweep had an effect on the proportions of clearcuttings recoverable in all length classes but caused a marked reduction in the longer lengths (Table 7 and Fig. 6). In the severely swept logs less than 10% of the outturn could be recovered in clear lengths greater than 3 m. The straight logs yielded around 22% in this category and moderately swept logs 14%.

TABLE 7—Clearcuttings distribution (% sawn volume)

Clearcuttings (m)	Straight logs			Moderately swept logs			Severely swept logs		
	Cpt 1	Cpt 36	Means	Cpt 1	Cpt 36	Means	Cpt 1	Cpt 36	Means
< 0.7	17.5	13.8	15.6	17.9	17.3	17.6	17.4	19.8	18.6
0.7–1.2	11.7	13.1	12.4	18.6	11.3	14.9	20.6	18.0	19.3
1.3–1.8	8.3	8.3	8.3	10.6	8.4	9.5	8.6	11.0	9.8
1.9–2.4	5.3	8.8	7.0	7.0	6.1	6.5	6.5	7.6	7.0
2.5–3.0	6.3	7.7	7.0	8.2	6.1	7.1	3.8	5.2	4.5
3.1–3.6	6.6	3.9	5.2	5.1	5.7	5.4	3.8	4.3	4.1
3.7–4.2	3.1	5.6	4.4	2.3	5.6	3.9	4.6	0.9	2.7
4.3–4.8	5.3	4.3	4.8	1.1	3.8	2.5	1.7	1.6	1.7
4.9+	7.1	8.5	7.8	0.4	4.1	2.2	1.2	0.7	0.9
Totals	71.2	74.0	72.5	71.2	68.0	69.6	68.2	69.1	68.6

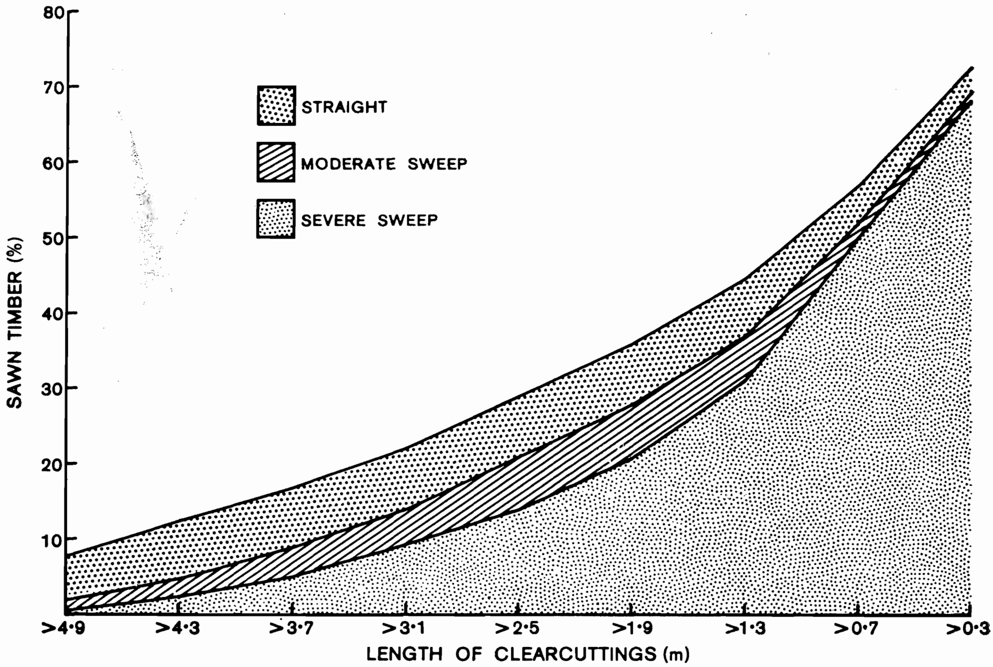


FIG. 6—Distribution of Clearcutting lengths.

Over-all, the proportions of cuttings available from the moderately and severely swept logs were 70% and 69%, respectively, of the sawn timber volume – only slightly less than the 72% from straight logs.

Timber and Log Values

Timber values ($/m^3 sawn) and log values ($/m^3 round) were calculated using Whiteside's (1982a) Price List B. Table 8 gives an indication of the effects of both log size and sweep.

On average, the value of the timber recovered dropped by 10% and 20%, respectively, for the moderately and severely swept logs compared to straight stems. The equivalent gross sawlog reductions were 18% and 33%.

Timber and log values increased markedly with increasing s.e.d. from the small to the medium-sized logs (38% and 45% respectively) but showed little further increase for the large logs. These trends presumably reflect the relationships between defect core size, log size, and conversion percentage in the particular samples used in the study, and the influence of the width premium in the price list.

Comparison of the log values with those given for similar log types by Park & Parker (1983) revealed an average difference of around 10% for the straight stems which has been attributed to the alternative edging practice adopted in the current study. This is in line with value increases reported for grade ripping of hardwood logs (Pnevmaticos & Bousquet 1972).

TABLE 8—Timber and log values

Sweep class	Log s.e.d. (mm)	Grade index	Timber value ($/m³)	Log value* ($/m³ round)
Straight	250–350	0.79	117	66
	351–450	1.03	165	103
	451+	1.01	169	106
Weighted means			158	97
Percentage			100	100
Moderate	250–350	0.65	108	56
	351–450	0.83	151	84
	451+	0.87	150	87
Weighted means			142	80
Percentage			90	82
Severe	250–350	0.60	102	50
	351–540	0.69	135	65
	451+	0.77	130	73
Weighted means			126	65
Percentage			80	67

* Including a credit of $12.5/m³ for sawmill residues.

Resin Pockets

All results in this study have been expressed "ignoring resin pockets" for the reasons given earlier. In practice there will often be some degrade from this defect and it should always be considered when making value predictions.

Timber value decreased by 4.3%, 5.6%, and 4.1% for straight, moderately swept, and severely swept logs, respectively, when the actual influence of resin pockets was included. There was no evidence to suggest any association between resin pocket incidence and either log size or sweep class. The highest individual log value reduction was 29%, but the unusual type of severe resin pocket found in some Mangatu butt logs by Vaney (1981) was not evident in any of the timber in this study.

Relationship Between Log Characteristics and Timber Outturn

The results presented so far have quantified differences between discrete groups of samples, e.g., by compartments, size classes, or sweep classes. One of the objectives of the study was to examine relationships which may enable the results to be applied to other situations where log characteristics are similar. To achieve this the data must be expressed in the form of predictive models.

The dependent and independent variables used to derive multiple regression equations are given in Table 9. Previous analyses of this nature have indicated that curvilinear relationships often give the best fit, so a number of transformations ($\log_e X$ and $1/X$) were included for each independent variable.

TABLE 9—Variables used in regression equations

Dependent variables		Independent variables
1. Timber value	($\$/m^3$)	1. SED (mm)
2. Conversion	(% round volume)	2. Log_e SED
3. No. 1 Clear	(% timber volume	3. 1/SED
4. No. 2 Clear	(% timber volume)	4. Defect core (mm) - DC
5. No. 1 Cuttings	(% timber volume)	5. Log_e DC
6. Factory	(% timber volume)	6. 1/DC
7. Merchantable	(% timber volume)	7. Sweep (mm/SED) - SW1
8. Box	(% timber volume)	8. Log_e SW1
9. No. 2 Clear +	(% timber volume)	9. 1/SW1
10. No. 1 Cuttings +	(% timber volume)	10. Sweep (mm/m) - SW2
11. Factory +	(% timber volume)	11. Log_e SW2
12. Merchantable + Box	(% timber volume)	12. 1/SW2
13. Clearcuttings	(% timber volume)	13. Taper (mm/m) - TPR
		14. Log_e TPR
		15. 1/TPR

SED = small-end diameter (mm)
DC = defect core (mm)
SW1 = sweep (mm/SED)
SW2 = sweep (mm/m)
TPR = taper (mm/m)

Results of the analyses are given in Table 10. Only variables significant at the 95% level or better appear in the table.

TABLE 10—Results of multiple regression analyses

Dependent variable	Independent variables	Correlation coefficient (r)	Residual standard deviation
Timber value ($\$/m^3$)	1/SED, DC, SW2, TPR	0.81	13
Conversion (%)	1/SED, SW2	0.88	4
No. 1 Clear (%)	1/SED, DC, SW2, TPR	0.75	10
No. 2 Clear (%)	1/SED, DC, SW2, TPR	0.46	6
No. 1 Cuttings (%)	1/SED, DC, SW2, TPR	0.43	8
Factory (%)	1/SED, DC, SW2, TPR	0.46	13
Merchantable (%)	1/SED, SW2	0.54	16
Box (%)	1/SED, DC, SW2, TPR	0.29	10
No. 2 Clear + (%)	1/SED, DC, SW2, TPR	0.74	12
No. 1 Cuttings + (%)	1/SED, DC, SW2, TPR	0.79	12
Factory + (%)	1/SED, DC, SW2, TPR	0.59	16
Merchantable + Box (%)	1/SED, DC, SW2, TPR	0.59	16
Clearcuttings (%)	1/SED, DC, SW2, TPR	0.87	4

Among the dependent variables used, relatively few gave r^2 values sufficiently high to be useful in prediction for individual logs. Fortunately, these are the most important, i.e., timber value, conversion percentage, No. 1 Clears, No. 2 Clears and better, No. 1 Cuttings and better, and percentage clearcuttings. It is to be expected, however, that the equations will be valid for predicting average grade recovery for batches of logs sawn to the same sawing pattern.

The log variables appearing consistently in the regressions are 1/s.e.d., defect core diameter, sweep (mm/m), and taper. Significant correlations can also be achieved using the sweep : s.e.d. ratio instead of sweep (mm/m) in most of the equations. In general, taper was the least significant variable in the regressions.

DISCUSSION AND CONCLUSIONS

Prediction of timber recovery and value from *P. radiata* pruned logs is at an early stage of development, and this trial represented the first comprehensive attempt to quantify the effects of log malformation. Previous work by Park (1980) and Park & Parker (1983) demonstrated the ability of a Grade Index to describe the quality of straight pruned logs sawn to 25-mm boards, and Whiteside (1982a) evaluated the effect of moderate sweep on timber recovery of logs cut to 50-mm timber.

The sampling strategy adopted in this study ensured the inclusion of a wide range of log sizes and sweep categories, but measurements of the defect core indicated that the two-lift pruning had resulted in a fairly uniform cylinder of knots and branch occlusions which may not be typical of logs from other two- or three-lift schedules. A different definition of defect core may be appropriate for such material. The arbitrarily defined "moderate sweep" (deviation D/4–D/3) and "severe sweep" (deviation greater than D/3) adequately covered the range of malformation in the stands surveyed and could provide a basis for defining pruned log grades. Detailed log measurements in the timber yard revealed that the visual sweep classes correspond very well to actual deviations of:

Straight –	< 10 mm/m
Moderate –	11–20 mm/m
Severe –	> 20 mm/m

The study results showed that log sweep can have a significant effect on both the amount and quality of timber recoverable from pruned butt logs. However, log size is also very important, and increasing diameter can compensate for a given degree of sweep. Another factor, which could not be adequately evaluated in this study, is mill throughput. With most mill designs, swept logs require more careful positioning during breakdown and this will involve reduced productivity. Dobie (1964) documented sawing times for a range of swept logs of *Pseudotsuga menziesii* in British Columbia and concluded that the average "sweepy" log required an additional 40% headrig time. Mill studies with *P. radiata* in New Zealand (unpubl. data) have revealed increased processing times ranging up to 30%, depending on log diameter. This obviously represents a substantial cost.

From a timber value standpoint, the medium and large severely swept logs in this study were more valuable than the small straight logs (Table 8) as a result of interaction between conversion percentage and grade returns. Average log values (using relative price indices) ranged from $50/m³ for small severely swept logs, to $106/m³ for large straight logs. Reductions in value of the order of 30% between straight and badly swept logs fully justify the use of sweep as a quality indicator. Both measures of sweep used in this study (sweep : s.e.d. ratio, and mm/m) proved to be useful in predictive equations.

Recoveries of the higher value products were closely associated with the measured log parameters, but the lower timber grades could not be accurately predicted. This is in line with previous studies.

All sample logs were 5.5 m long, corresponding to the pruned portion of the stems. However, it is widely recognised that the influence of sweep can be dramatically reduced by decreasing the log length. In fact, most of the severely swept logs in this study (average sweep 30 mm/m) would yield two, nominally straight, 2.7-m logs (average sweep 7.5 mm/m). This may be an attractive option where recovery of clears and clearcuttings is a primary objective. Not only would this result in improved grade returns, but it would also increase the conversion percentage.

Although many of the effects of sweep were clearcut in this study, the complexity of interactions between log parameters, processing standards, recovery practices, and price assumptions must be borne in mind (Whiteside 1982a). Future studies will extend the pruned log data base and cover a greater range of swept log types, particularly as regards defect core profile. Headrig processing times will also be closely monitored in relation to log sweep and sawing patterns.

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