RECOVERY OF CLEAR LENGTHS FROM PRUNED PINUS RADIATA SAWLOGS

J. C. PARK

Forest Research Institute, New Zealand Forest Service,
Private Bag, Rotorua, New Zealand

(Received for publication 17 May 1985)

ABSTRACT

Results from analysis of 165 pruned **Pinus radiata** D. Don butt logs, drawn from 11 forests and converted by one standardised sawpattern, were used to introduce the concept of evaluating sawn produce by recoverable clear lengths. Samples represented the range of straight pruned log types expected from the "Transition Crop". Clears and clearcuttings were expressed as distributions, by percentage of round log volume, in nine nominated clear length classes. The effects of extracting clear lengths on over-all conversion, consequent volumes of defecting waste, and numbers of crosscuts to be made on boards were also determined. Volumes in each clear length class, defecting waste, and numbers of crosscuts required were all found to be predictable and have been modelled.

The predictive models derived adequately identified the clearwood which could be sawn from the range of pruned log types investigated. Comparisons with earlier results showed the clearwood potential of a large proportion of the "Transition Crop" logs was poorly represented under standard timber grades. Therefore it is proposed that appraisal of pruned sawlogs by their recoverable clearwood becomes standard practice. This would provide both an alternative and a complement to evaluations by timber grades, and promote better understanding of the potential of various pruned log types for sawn timber.

Keywords: Pinus radiata; pruned logs; sawing; timber grades; clear lengths; log conversion; clearwood factor; defect-free clears; defecting.

INTRODUCTION

The conventional method of evaluating pruned stems as sawlogs is to conduct timber grade studies and analyse grade distributions; values are derived from a timber price list based on differentials between the various grades. To date there have been no New Zealand standard rules specifically designed for timber from pruned softwood logs but the rules are currently under review and accommodation of pruned produce is expected in the near future. The existing rules (NZS 3631 : 1978) adequately describe the lower-value produce – viz Factory, Merchantable, and Box grades – but have no definition for clear or mainly clear grades. Results from timber grade studies on pruned logs have, until now, been facilitated firstly by defining Clears as completely defect-free (e.g., Fenton 1967; Park 1980), and more recently by using the provisional "Clears

Grades" of Whiteside (1982a) to define the most valuable grades. To explain grade outturn and to assist in predictions of Clears grades "off the saw" (i.e., not considering any form of defecting or docking for grade improvement), the term "defect core" was derived. Defect core was defined as:

> ". . . the 'cylinder' containing pith, branch stubs, and occlusion scars. It included any widening effects due to stem sinuosity at the time of pruning. The size of this core was expressed by its diameter (in mm)" (Park 1980).

This term is now well established in New Zealand but its limitations are not always appreciated. While defect core is essential to formulae for predicting Clears grades "off the saw", it becomes inadequate if docking for grade or crosscutting boards for clear lengths is considered. These options demand more detail on the size and shape of the pruned core resulting from each pruning lift.

Most pruning produces irregularly shaped cores. Where pruning lifts have been applied in a progressively belated manner, cores have an umbrella shape and large volumes of long clear lengths exist inside the defect core. Because such pruning has been typical in the past, the majority of No. 1 Clears expected from the current pruned resource will be less than full pruned-log length. A series of timber grade studies on "Transition Crop" *P. radiata* grown throughout the country has shown what can be expected from pruned logs over the next 10 years (*see* Fig. 1). About two-thirds of No. 1 Clears "off the saw" will be in shorts and random lengths from the outside and tapered sections of logs. Shorts are defined here as timber less than half log length; random lengths are all other pieces less than full length.

The prime reason for pruning *P. radiata* in New Zealand is to produce clearwood, most of which is aimed at the export market. Timber is a bulky commodity and therefore it should be important to offset high transport costs by shifting only high-value produce. Full-length clears will be in short supply. Log length timber in Cuttings grades, i.e., mainly clear but with some major defects, is an unlikely prospect for export. The naturally arising proliferation of short and random length clears is also unlikely to be attractive to overseas merchants and would present problems for efficient packaging and transport. Squared packets and snug container loads may comprise a variety of timber widths and thicknesses providing lengths are standardised. Thus, the recutting of random length clears to predetermined standard lengths for export seems inevitable. Such standardisation may also be preferred by the domestic market. Once the need for some crosscutting is established, the next logical step is to consider defecting at least some of the lower grade pieces to produce equivalent clear lengths.

Some New Zealand mills are already cutting very short clear components for export from timber sawn from unpruned logs. The common length range produced by this operation is 400–1800 mm and a length premium has become established across this range. Standardised clear lengths docked from the sawn produce of pruned logs should offer advantages both in supplying longer lengths and in meeting multiples of any shorter lengths for which preferences may be shown.

This paper proposes an alternative to the traditional evaluations of pruned sawlogs via timber grades. Pruned logs are viewed in terms of the percentage of clears and clearcuttings which may be recovered. Results from 12 timber grade studies on pruned

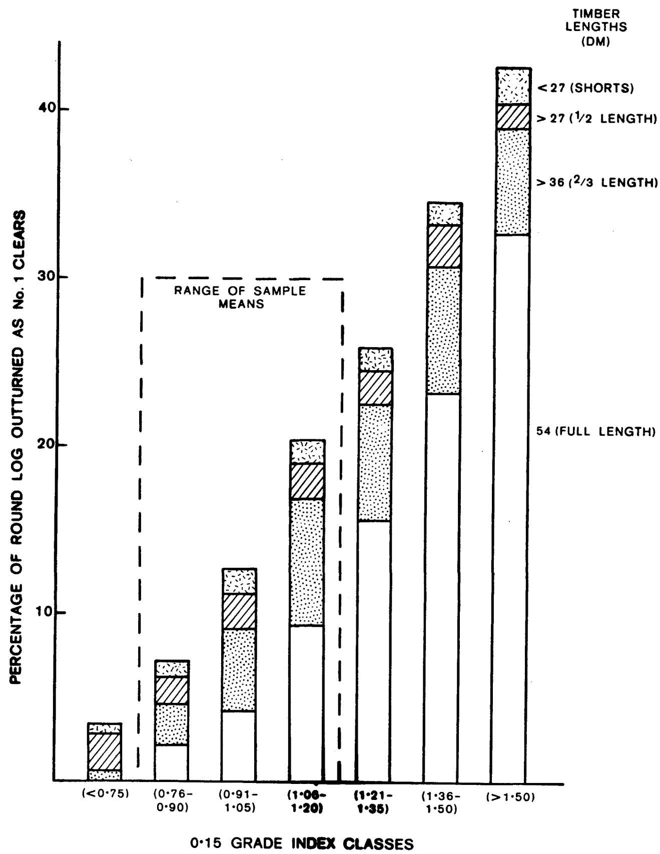

FIG. 1—Outturn in No. 1 Clears (as defined by Whiteside 1982a) by 0.15 Grade Index (Park 1980) classes. These are aggregated results from 12 grade studies on "Transition Crop" samples. The range of sample means are included to indicate that about two-thirds of No. 1 Clears "off the saw" are expected as shorts and random lengths.

P. radiata butt logs have been re-analysed in terms of the clear lengths found in all produce. These studies constitute a cross-section of the straight pruned log types expected over the next 10 years from the "Transition Crop". No attempts have been made to assign dollar values to the range of clear pieces found or to attribute costs to the docking and defecting operations needed for total clearwood recovery. Both are complex subjects and so require separate analyses similar to those carried out on the economics of fingerjointing by Maplesden & McConchie (1984). However, sufficient information is given here to allow readers to make estimates of defecting costs and resulting product value based on their own information or assumptions.

While appraisal of pruned sawlogs by their recoverable clearwood is proposed here as an alternative to evaluation by timber grades, it is not proposed as a replacement. Rather, the two approaches are complementary and, if used together, will provide a more complete understanding of the potential of various pruned log types for sawn timber.

EXPERIMENTAL PROCEDURE AND RESULTS

Objectives

Primary objectives were to investigate the distributions, by volumes and lengths, of all clears and clearcuttings which could be recovered from a range of pruned butt logs; and then to show that these could be predicted or estimated from information on pruned crops combined with information on sawing procedures and sawmill efficiency. Secondary objectives were to determine the effect of defecting on conversion and the numbers of crosscuts required.

There are various approaches to making predictions of recoverable clearwood and the method employed here is not claimed as either the only or the most appropriate one for all circumstances (this is further explored in the Discussion at the end of this paper). It does, however, lend itself to straightforward demonstrations of basic principles and a realistic ranking of logs by their clearwood potential. For the sake of simplicity, results have been limited to one interpretation of basic formulae by holding the following variables constant – log length, log straightness, sawpattern, and sawing to nominal size with no overcut.

The Samples

From 1978 to 1983 a series of sawing studies was run in which "nominally straight" pruned *P. radiata* butt logs were sawn to boards under a standardised sawpattern. "Nominally straight" for these studies has been defined as logs with a sweep ratio (sweep ÷ s.e.d.) not exceeding 0.20. The mean sweep ratio from all samples was 0.08. The data base assembled from the 18 studies completed contained a total of 262 logs ranging in length from 4.9 m to 5.5 m. Results by timber grades have been given by Park (1980), Whiteside (1982b), and Park & Parker (1983).

All 5.5-m logs which had been sawn accurately to size were extracted from the data base. The total was 165 logs from 12 studies which represented "Transition Crops", grown under a variety of silvicultural schedules, from eight locations in the North Island and four in the South Island. In each study, logs had been selected to span the sawable size range of pruned logs in the stand sampled. Sample size ranged from nine to 24 logs, log size from 29 to 89 cm d.b.h., the age of stands from 21 to 39 years. A summary of sample logs is given in Table 1.

Sawing

Two mills in the North Island and two in the South Island were used to convert logs. The factors common to each of these were a band headrig and mobile carriage, and the ability to cut accurately to size.

All logs were flat-sawn exclusively to 25-mm boards. An objective in sawing was to contain as much of the defect core as possible in the cant. Cant sizes ranged from 100 to 300 mm, in increments of 50 mm, depending on the size of defect cores encountered. An example of this sawing pattern is included in Fig. 2. The stated objective in edging was to recover the widest boards possible (up to 30 mm max.) without losing volume, i.e., not to edge for grade.

TABLE 1—Summary of sample logs (log length 5.5 m)

Sample location	Number of logs	Age (years)	Range of samples: d.b.h. (mm)	Range of samples: Aggregate defect cores (mm)	Range of samples: Number of pruning lifts
Kaingaroa Cpt 1250	23	22	320–725	170–434	2
Waiotapu Cpt 28	24	38	423–885	168–469	2 (21 logs) 3 (3 logs)
Patunamu Cpt 3	12	28	448–698	176–374	2
Mangatu Cpt 1	12	21	291–539	187–330	2
Waiuku Cpt 35	10	27	526–682	263–321	2 (3 logs) 3 (7 logs)
Golden Downs Cpt 116	15	22	378–501	152–284	2 (13 logs) 3 (2 logs)
Golden Downs Cpt 95	8	25	362–445	210–242	2
Herbert Cpt 21	15	26	395–559	173–263	3
Rankleburn Cpt 5	9	26	390–603	158–249	2
Whakarewarewa Cpt 15	13	39	501–695	238–371	3
Rotoehu Cpt 51	14	30	414–697	233–378	2
Waikite (shelterbelt)	10	22	560–800	255–527	3
All samples	165	21–39	291–885	145–527	2 and 3

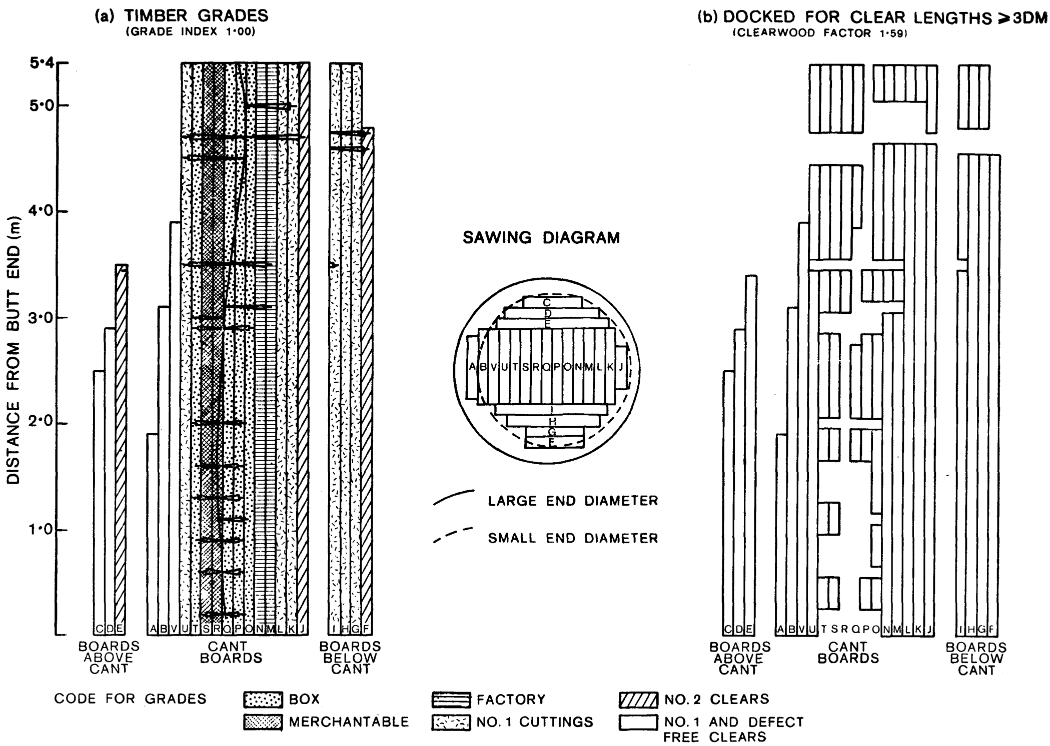

FIG. 2—Comparison of recovery in timber grades "off the saw" and recovery by clear lengths from Log 58 drawn from Waiotapu Forest. This log was pruned in three, progressively belated lifts.

Timber Analysis

All studies were carried out using the methods of Park & Leman (1983). In addition to producing individual log timber grade distributions, the methods included detailed mapping of defect cores and derived distributions of clear lengths (down to a minimum of 3 dm) for each log. Figure 2 demonstrates the detail of data collected and the capability of the method to evaluate logs by clear lengths as well as by timber grades. The Figure was constructed from basic data gathered on one of the Waiotapu sample logs. This log was deliberately chosen to also serve as an example of the effects of progressively belated pruning.

The computer program which completes basic timber analysis produces two sets of results, the first including the degrading effects of resin pockets and the second excluding these. Resin pockets have been ignored in the results presented here because the variation in incidence between samples would otherwise confound these results. Clearwood reduction factors for resin pockets must be derived on a stand-by-stand basis.

Derivation of a Clearwood Factor

The potential of pruned butt logs to yield sawn clearwood depends mainly on their form, length, and size, and the size and shape of their defect cores. In these studies logs were nominally straight and length was standardised at 5.5 m. Log size was expressed by diameter at breast height, i.e., the measurement point used when trees are standing. Many expressions of defect core size and shape were tested, most based on various aggregations of partial defect cores. A partial defect core was defined as the 'cylinder" which, over the effective length of one pruning lift, contained pith, branch stubs, and occlusion scars. The size of a partial defect core was expressed by its diameter (in millimetres). Initial consideration given to differences in nodal habit was not pursued because the data base showed that most 5.5-m butt logs carried between eight and 13 whorls, irrespective of geographic location or site. A simple weighted mean of partial defect cores proved as adequate as combinations by more complicated formulae. Weighting was determined by the proportion of total log length each partial defect core occupied. This new expression of internal log features has been named aggregate defect core. Because of the factors held constant among the samples analysed here, their clearwood potential could be simply expressed as the ratio of d.b.h. to aggregate defect core.

When only one sawpattern is applied and sawmill standards are similar, the difference between log potential and realisation is explained mainly by differences in conversion; clearwood yields can be explained or predicted by a formula combining log potential with log conversion.

$$\text{clearwood factor} = \frac{\text{d.b.h.}}{\text{aggregate defect core}} \times \text{log conversion}$$

Results

The details of data collected from the pruned logs sampled offered a wide range of possibilities for predicting clear lengths and so a decision was required as to what form the results should take. The minimum clearcutting length measured on boards was 3 dm so this set the lower limit. A basic unit of 6 dm was chosen for all other lengths because multiples of this include frequently used furniture components and the standard stud length. Thus, with the exception of the shortest length (3 dm), the aim was to predict volumes of clear timber available in each of the multiples of 6 dm. Rather than limit results to one interpretation of clear lengths for each piece of timber, predictions have been made cumulative, e.g., clear volumes in the longest length class were also included in all other length classes.

A clearwood model (total defecting for clears)

For each log, clearwood volumes by length classes were converted to percentage of round log volume. A model, based on the clearwood factor, was constructed using a modification of the Gauss-Newton method of non-linear regression analysis (Hartley 1961). Plots of data points and the lines fitted for each 6-dm length class are shown in Fig. 3. The complete model for recoverable clearwood is presented as Fig. 4. It includes an estimate for total log conversion in order to identify the amount of docking waste total recovery of clear lengths would incur. Equations for the model are given in Table A1 Appendix 1.

A comparison between volumes in recoverable clear lengths and volumes outturned as clear timber grades "off the saw" has been made to put results into perspective. Because the clearwood factor is inappropriate as either an expression or a predictor of clears "off the saw" a direct graphical comparison using the same axes was not possible. The solution was to present a complementary Figure using the same vertical scale (i.e., percentage of round log volume) against an expression designed for undocked timber grades. Therefore, the relationship between Grade Index (Park 1980) and timber grades from pruned logs which are clean on both faces has been reproduced from Park & Parker (1983). The prediction for both Defect Free Clears and No. 1 Clears is shown in Fig. 5.; timber grades which are not clean are also shown as the accumulated balance. Although the clearwood factor used and Grade Index are not direct equivalents, Fig. 4 and 5 respectively display the complete range of each as found in these samples. The most valid comparison of recoverable clear lengths (Fig. 4) is with the Defect Free Clears (Fig. 5) as both are entirely free of defects on all edges and faces. This comparison shows that the varying lengths of Defect Free Clears recovered "off the saw" represent only about half the volume of specific clear lengths that could be recovered with the assistance of docking. No. 1 Clears (Fig. 5), although classified as clean, are not truly clear. They are advantaged by the allowance of a few minor defects but still do not compare favourably with recoverable clear lengths (Fig. 4) if the aim is to maximise clearwood.

A crosscutting model

The complement to defining volumes and distributions of available clear lengths is a method of showing the amount of effort required to recover these. Therefore, a second clearwood-factor-based model was constructed to give, for the sawpattern used, estimates of the number of crosscuts required to recover clear lengths by each of the 6-dm classes (Fig. 6, and Table A2 Appendix 1). Predictions are in the form of the number of crosscuts required on "off the saw" produce recovered from 1 m^3 of a pruned log type. These estimates were derived by attributing two cuts for each of the

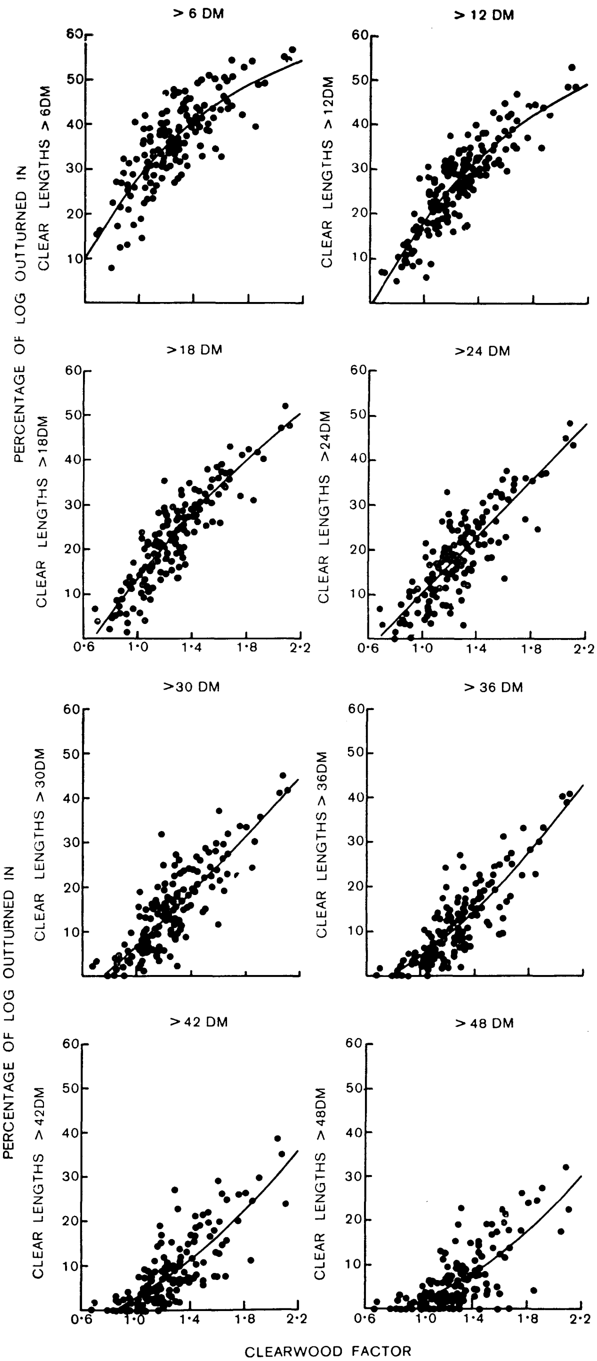

FIG. 3—Plots of data points and lines fitted for relationships between the clearwood factor and recoverable clear length classes.

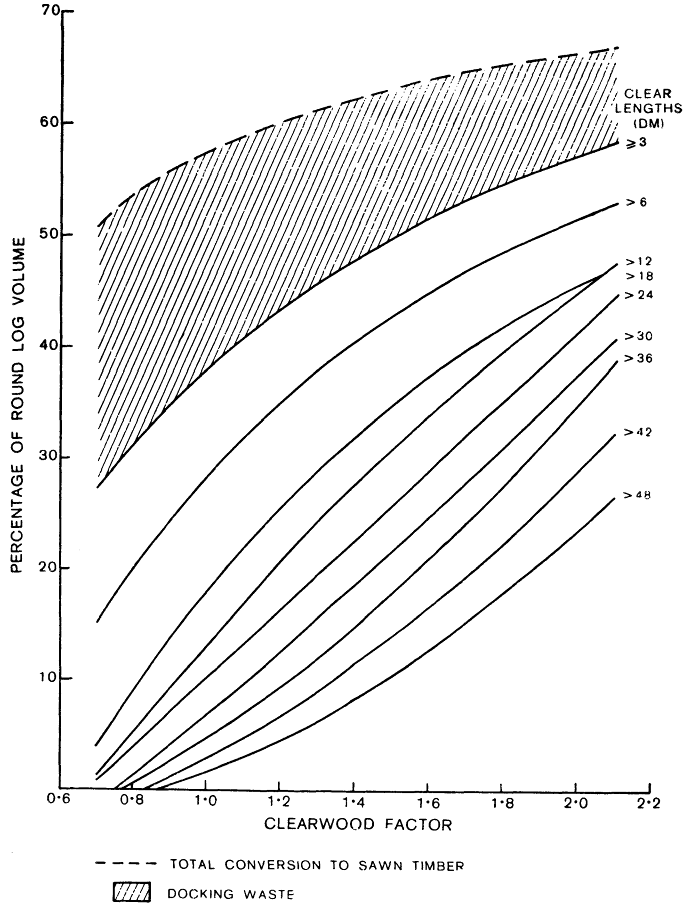

FIG. 4—The clearwood model for recoverable clear lengths.

clears and clearcuttings identified in the data base. For clearcuttings two cuts are necessary to extract the piece; for clears a cut across each end ensures a squared up and standardised product. The choice of expression for numbers of crosscuts required was designed to be compatible with the model predicting clearwood in order that the two could be used together.

Use of clearwood and crosscutting models in combination

By selecting a clearwood factor and substituting in equations from Table A1 Appendix 1, the potential for clear length recovery can be calculated. Substitution of the same clearwood factor in equations from Table A2 Appendix 1 derives an estimate of the number of crosscuts required on boards to produce the clear lengths. The results of an exercise using the models in combination and taking a low, a medium, and a high clearwood factor are given as an example in Table 2. Information in this form is immediately useful for exercises on valuing and costing this alternative to standard timber grades and so would assist in any future comparisons of the two options.

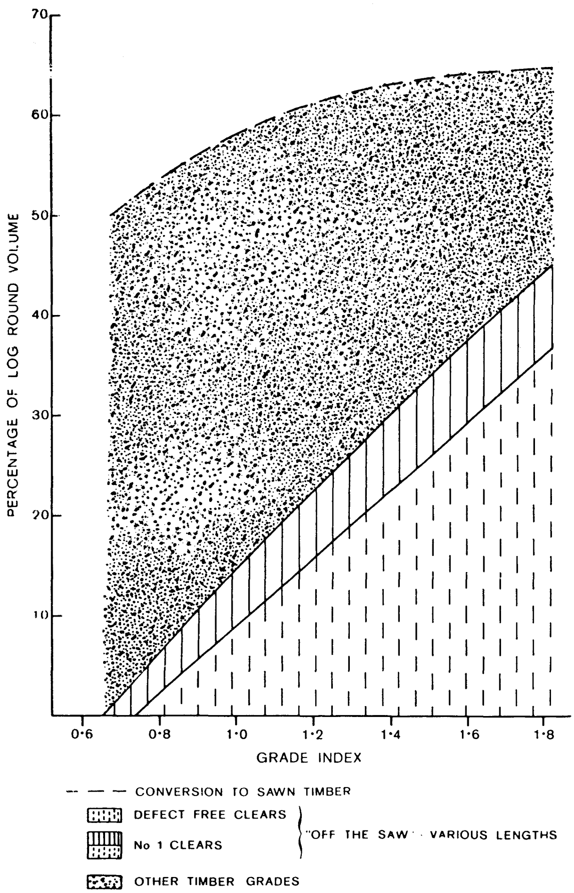

FIG. 5—Outturn in clear timber grades "off the saw" predicted by Grade Index (reproduced from Park & Parker 1983).

Mixing clear length recovery and timber grade options

When pruning has been poor (i.e., at low clearwood factors), proportions of the shorter clear lengths, docking waste, and number of crosscuts required are all very high (Fig. 4 and 6, Table 2). This is because there is little difference, in terms of short clearcuttings, between poorly pruned and unpruned logs. Even at higher clearwood factors the amount of effort required to recover the shorter lengths and consequent high proportions of docking waste may be considered as only marginally acceptable. A preference may be to leave the knottiest boards, and those containing pith, as full-length low-grade timber and thus restrict the extraction of clear lengths to the produce which shows definite benefits from pruning. There could be many variations on mixing the timber grade and clear length recovery options. For example, docking for clears could be nominated to replace specified timber grades from all pruned logs or may be restricted to total docking for clear lengths on "suitable" pruned log types; or may be specified as some combination of these two criteria. Decisions on choices would be

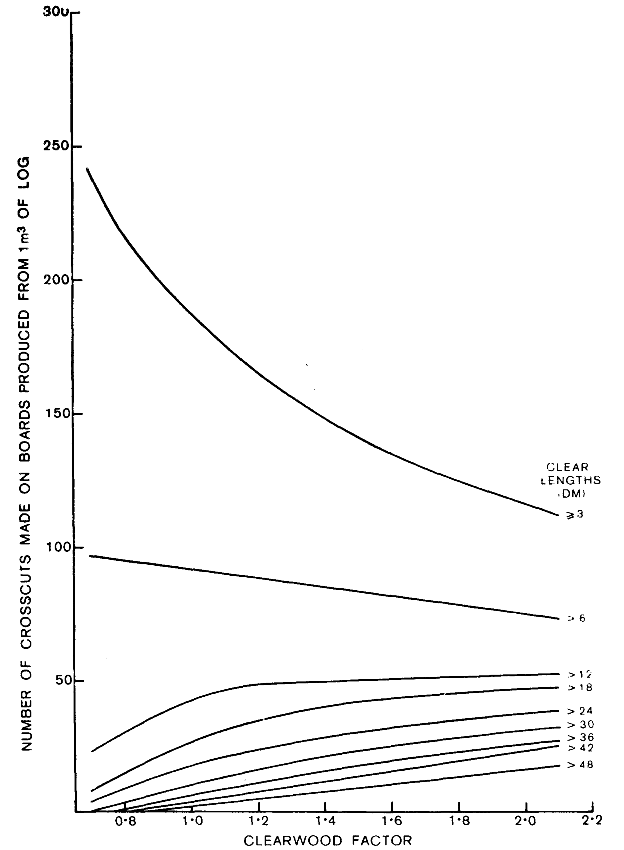

FIG. 6—The crosscutting model; number of crosscuts required to extract clear lengths from the sawn produce outturned per cubic metre of log.

TABLE 2—Example of combined use of clearwood and crosscutting models

Clear length class (dm)	C.F.*	Clear† (%)	Cross-cuts‡ (No.)	C.F.	Clear (%)	Cross-cuts (No.)	C.F.	Clear (%)	Cross-cuts (No.)
≥3	0.8	31.2	219	1.4	48.1	148	2.0	57.4	115
>6	0.8	20.0	95	1.4	40.7	84	2.0	51.8	74
>12	0.8	9.3	30	1.4	32.1	50	2.0	45.8	51
>18	0.8	5.3	15	1.4	27.7	39	2.0	45.4	46
>24	0.8	3.9	9	1.4	22.8	28	2.0	41.7	36
>30	0.8	1.3	4	1.4	18.8	21	2.0	37.9	31
>36	0.8	0.6	1	1.4	15.0	15	2.0	35.3	25
>42	0.8	–	–	1.4	11.6	11	2.0	29.1	22
>48	0.8	–	–	1.4	8.4	8	2.0	23.7	16

* Clearwood factor

† Prediction of log conversion to clear lengths (from Table A1 Appendix 1)

‡ Prediction of number of crosscuts required on boards to extract and/or trim clear lengths (from Table A2 Appendix 1).

influenced by such factors as the price for clear material, the strength of preference for standardised clear lengths, the magnitude of length premiums, and whether or not large quantities of low-grade timber could be satisfactorily quitted. A simplistic example is presented here to demonstrate some of the effects, and potential advantages, of mixing clear length recovery and timber grade options.

All logs were included in this example and treated in the same manner. Boards which are graded out as Merchantable and Box under NZS 3631 : 1978 were retained as "off the saw" produce (being from the centre of logs these boards were nearly all full length). All higher-grade boards were "reduced" to the clear lengths they contained. A third clearwood factor-based model was constructed from the results of this mixed option (Fig. 7, and Table A3 Appendix 1).

In comparing results from the mixed option (Fig. 7) with those from total clear length recovery as shown in Fig. 4, the following should be noted:

(a) There is a large reduction in docking waste;

(b) There is a large increase in total timber recovered;

(c) There is a large reduction in the two shortest clear lengths recovered;

(d) Recovery of clear material in the intermediate length classes is similar;

(e) Recovery of clear material in the four longest classes remains exactly the same.

A reworking of crosscutting data to produce an equivalent of Fig. 6 for this example of a mixed option was deemed unnecessary. Estimates for the number of crosscuts required on all except the two shortest clear length classes would be almost the same. The disproportionate effort involved in extracting the two shortest length classes would be minimised in proportion to their reduced recovery.

DISCUSSION

The range of pruned logs re-examined here can be taken as a fair representation of the straight logs expected from "Transition Crops". Most clears produced "off the saw" will be in random lengths and, under standard timber grading, a large amount of potentially clear material will be absorbed in mediocre grades. The alternative of crosscutting pieces for clear lengths would benefit some pruned log types more than others; if logs were large and straight with small regular-shaped defect cores, differences in clears recovery between the two options would be minimal. Unfortunately this is rare and stems which experienced progressively belated pruning (e.g., Fig. 2), virtually demand some degree of docking for clear lengths. Decisions on whether to present sawn produce by timber grades or as standardised clear lengths would be strongly influenced by the characteristics of a particular batch of pruned logs and market preferences at the time. Compromises, such as the example of mixing options given earlier, offer a large and interesting range of possibilities.

Swept logs were not included in the demonstrations here because complementary data presently available on these are limited to results from just a few types of silviculture. Nevertheless, sweep is known to lower conversions and reduce recoveries in clear timber grades; but while sweep also reduces the lengths of clearcuttings, it has little effect on the proportions of total sawn volume these represent (Cown *et al.* 1984).

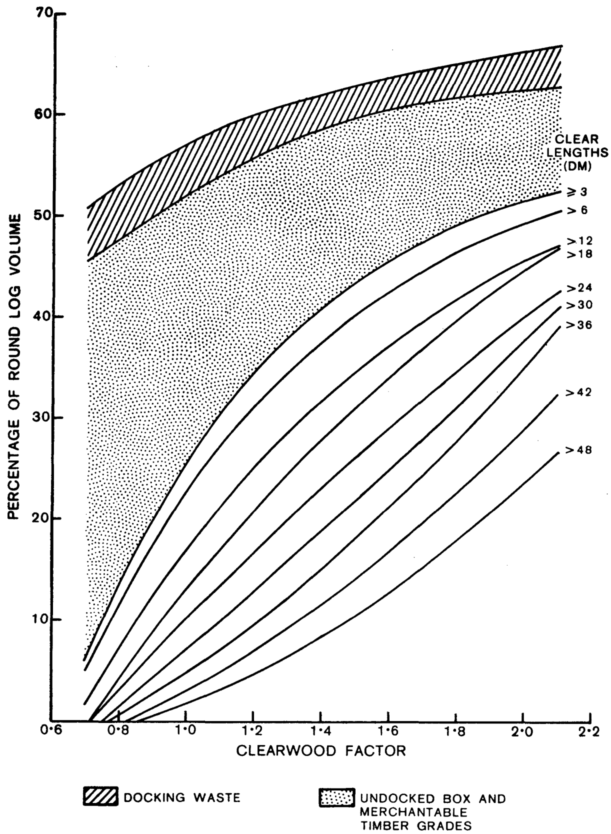

FIG. 7—A mixed clear length recovery and timber grade option. Box and Merchantable timber grades are retained; all other sawn produce is docked for clear lengths.

In other words, similar percentages of the sawn outturn from swept logs would be in recoverable clear lengths but these would tend to be shorter than those from straight logs.

While these results give a useful perspective to the "Transition Crop" and effectively rank various pruned log types by the clearwood potential, they are obviously very limited, particularly from a sawmiller's point of view. Interpretations have been restricted to clear volumes by length classes produced from one 25-mm sawing pattern. Specific widths and thicknesses are equally important to production of clear components but these are governed by sawpattern. To provide complete information it will be necessary to reinterpret basic formulae for a range of sawpatterns. The choice of these sawpatterns would be governed by commercial practicability in the mill and the complete dimensions of clear components demanded or preferred by the market. Predictions of outturn for other sawing patterns could be gained by two methods. The first is to complete batches of sawing studies on each sawpattern chosen; a very lengthy and expensive process. Simulated sawing of well-described individual pruned logs provides a more realistic alternative. Such computer simulation packages are currently being developed at FRI and are being designed to accept as input logs sawn, reconstructed, and described by the methods of Park & Leman (1983) (which also includes all those used as basic data in this paper), and logs cross-sectionally analysed by the system of Somerville (1985).

The clearwood factor used here was derived to demonstrate that recoverable clear lengths can be predicted. Being a single expression of pruned log potential it is also a useful complement to Grade Index. However, the most important conclusion here is that sawing predictions on pruned logs should henceforth include estimates of recoverable clear lengths. Some variations on the methods used here may be more convenient for, or compatible with, existing complex computer systems for predicting a spectrum of sawing results, e.g., PREVAL (Whiteside 1982b), or those being developed. A variety of mechanisms to express and interpret the interactions of the three important variables – log size, aggregate defect core size, and log conversion – should give comparable results.

ACKNOWLEDGMENTS

The assistance of the numerous FRI and Conservancy staff who were involved with the basic data collection and timber studies is gratefully acknowledged. The author is also grateful for the co-operation received from the following sawmills: TITC, Waipa; Bay of Islands Sawmill; C. Aitkenhead and Sons, Pokeno; Donelly's, Nelson; Rosebank Davy's, Balclutha. A major contribution to results was made by C. E. Mason who assisted in most phases of the studies and attended to all computing needs.

REFERENCES

COWN, D. J.; McCONCHIE, D. L.; TRELOAR, C. 1984: Timber recovery from pruned **Pinus radiata** butt logs at Mangatu: Effect of log sweep. **New Zealand Journal of Forestry Science 14:** 109–23.

FENTON, R. 1967: A timber grade study of first rotation **Pinus radiata** (D. Don) from Kaingaroa Forest. **New Zealand Forest Service, Forest Research Institute Technical Paper 54.**

HARTLEY, H. O. 1961: The modified Gauss-Newton method for the fitting of non-linear regression functions by least squares. **Technometrics 3(2):** 269–80.

MAPLESDEN, F.; McCONCHIE, J. 1984: The economics of fingerjointing for the production of clearwood. **New Zealand Forest Service, FRI Bulletin No. 63.**

PARK, J. C. 1980: A Grade Index for pruned butt logs. **New Zealand Journal of Forestry Science 10:** 419–38.

PARK, J. C.; LEMAN, C. S. E. 1983: A sawing study method for evaluating timber from pruned logs. **New Zealand Forest Service, FRI Bulletin No. 47.**

PARK, J. C.; PARKER, C. E. 1983: Results from regional validation studies of pruned radiata pine butt logs sawn to boards. **New Zealand Forest Service, FRI Bulletin No. 48.**

NEW ZEALAND STANDARDS INSTITUTE 1978: "Classification and Grading of New Zealand Timbers". (National Timber Grading Rules) NZS 3631 : 1978. Standards Association of New Zealand. 91 p.

SOMERVILLE, A. 1985: The field procedure for the cross-sectional analysis of a pruned radiata log. **New Zealand Forest Service, FRI Bulletin No. 101.**

WHITESIDE, I. D. 1982a: Clear grades of radiata pine timber – development and evaluation of grading rules. **New Zealand Forest Service, FRI Bulletin No. 1.**

——— 1982b: Predicting radiata pine gross sawlog values and timber grades from log parameters. **New Zealand Forest Service, FRI Bulletin No. 4.**

APPENDIX 1

TABLE A1—Equations to support Figure 4

Length class (dm)	Equation	Coefficients a	b	c	r^2	rms
CLEARWOOD MODEL x = clearwood factor y = percentage of round log volume in clear lengths n = 165						
≥3	$y=a+be^{-cx}$	68.73	-83.57	0.999	0.628	22.65
>6	$y=a+be^{-cx}$	64.29	-102.9	1.053	0.641	31.52
>12	$y=a+be^{-cx}$	66.57	-112.8	0.847	0.773	21.53
>18	$y=a+be^{-cx}$	113.1	-146.9	0.387	0.797	21.31
>24	$y=a+bx$	-21.29	31.49		0.714	28.32
>30	$y=a+bx+cx^2$	-19.64	24.53	2.109	0.706	27.30
>36	$y=a+bx+cx^2$	-9.624	6.306	8.065	0.732	20.88
>42	$y=a+bx+cx^2$	-7.326	2.414	7.907	0.653	21.71
>48	$y=a+bx+cx^2$	-2.336	-4.909	8.958	0.573	20.31
TOTAL LOG CONVERSION TO TIMBER x = clearwood factor y = conversion (%) n = 165						
	$y = \frac{x}{a + bx}$	0.00491	0.01262		0.257	27.73

TABLE A2—Equations to support Figure 6

Length class (dm)	Equation	Coefficients a	b	c	r^2	rms
CROSSCUTTING MODEL x = clearwood factor y = number of crosscuts on boards sawn from 1 m^3 of log n = 165						
≥3	$y=ax^b$	187.3	-0.699		0.324	1238
>6	$y=a+bx$	109.3	-17.83		0.043	499.4
>12	$y=a+be^{-cx}$	51.28	-626.2	4.219	0.215	114.6
>18	$y=a+be^{-cx}$	49.30	-157.7	1.921	0.485	59.47
>24	$y=a+be^{-cx}$	43.30	-98.07	1.519	0.464	48.64
>30	$y=a+be^{-cx}$	43.88	-83.61	0.920	0.534	34.48
>36	$y=a+be^{-cx}$	48.47	-77.53	0.606	0.591	22.65
>42	$y=a+bx$	-14.52	18.49		0.543	20.48
>48	$y=a+bx$	-11.44	13.86		0.470	15.43

TABLE A3—Equations to support Figure 7

Length class (dm)	Equation	Coefficients a	b	c	r^2	rms
MODEL OF MIXED OPTION (Box and Merchantable grades, undocked) x = clearwood factor y = percentage of round log volume in clear lengths n = 165						
≥ 3	$y = a + be^{-cx}$	58.05	-161.7	1.606	0.691	36.73
>6	$y = a + be^{-cx}$	58.60	-138.6	1.350	0.699	34.14
>12	$y = a + be^{-cx}$	62.84	-121.0	0.972	0.778	22.88
>18	$y = a + be^{-cx}$	84.95	-128.0	0.578	0.789	23.27
>24	$y = a + bx + cx^2$	-27.86	41.75	-3.883	0.717	28.44
>30	$y = a + bx + cx^2$	-19.64	24.53	2.109	0.706	27.30
>36	$y = a + bx + cx^2$	-9.624	6.306	8.065	0.732	20.88
>42	$y = a + bx + cx^2$	-7.326	2.414	7.907	0.653	21.71
>48	$y = a + bx + cx^2$	-2.336	-4.909	8.958	0.573	20.31
PRODUCE RECOVERED AS UNDOCKED BOARDS x = clearwood factor y = percentage round log volume outturned in Box and Merchantable grades						
	$y = a + \frac{b}{x}$	-4.714	31.31		0.269	27.46
TOTAL LOG CONVERSION TO TIMBER x = clearwood factor y = conversion (%)						
	$y = \frac{x}{a + bx}$	0.00491	0.01262		0.257	27.73