CLASSING PRUNED LOGS AND BENCHMARKING SAWMILL RECOVERIES

J. C. PARK
Ministry of Forestry, Forest Research Institute,
Private Bag 3020, Rotorua, New Zealand

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ABSTRACT

Data on 357 logs from 25 standardised timber grade studies (including **Pinus radiata** D. Don, **Cupressus macrocarpa** Hartweg, and **Cupressus lusitanica** Miller) were used to derive methods of classifying pruned sawlog samples and rating sawmill recoveries in pruned log conversion. Results from SEESAW simulations were used to set upper benchmarks for total conversion and recovery in clears grades. Six pruned log classes, ranging from "unpruned" through to excellent, were established. Sample means from the 25 studies were represented in five of these classes demonstrating the wide range of pruned log quality currently available in New Zealand. However, over half the sample means were grouped within the third lowest class and a further quarter were in the class below that, which confirms well-pruned logs are still scarce.

Large differences in mill conversions and clears grades recovery were also identified. This was demonstrated by comparing results from five sawmills with the simulation-established benchmarks. On similar log types, clears grades recovery from the best-performed mill came within 4.5 percentage points of the benchmark while the worst mill was down 18.4 percentage points. Such diversity in results demonstrated why the quality of pruned logs should be assessed on their potential rather than on grade recovery by any particular mill.

Keywords: pruned sawlogs; Pruned Log Index; timber grade recovery; sawing simulation; SEESAW.

INTRODUCTION

Two major considerations in pruned sawlog trading are:

- What quality are the logs?
- What percentage of clears grades can the mill expect to recover?

The first consideration is quite straightforward. What is required is a definition of pruned log quality based on the potential for producing clears grades timber. This was addressed earlier (Park 1989a) with the derivation of a Pruned Log Index (PLI) based on measurements of log size and shape and the size of the defect core. The applications and adequacy of this index to pruned resource evaluations were examined and confirmed in a case study (Park 1989b).

The second consideration is more complicated as the result differs among sawmills. There can also be major differences between what a mill could recover and what is practical under its current operating constraints. For example, a throughput-orientated production mill may not be in a position to expend the time required to grade saw pruned logs competently. Consequently, that mill's clears recovery from top-quality pruned logs may only equal recovery gained from mediocre logs by another mill geared for high conversions and grade sawing. It is readily conceded that grade recovery is but one of many factors to be considered in the efficient operation of a sawmill, and that its importance may vary according to the relative importance of many other factors. But general sawmill efficiency is not the subject here. Neither does this paper attempt to make judgement on which mills should saw pruned logs or on what level of clears recovery should be achieved. Rather, the aim is to illustrate and quantify the wide range of differences which have been experienced, in various mills around the country, during timber grade studies. These differences have direct implications for pruned log trading practices.

It has been a frequent practice in the past to set or adjust log prices according to mill output. This originated with the milling of native timbers and may have been the only practical option for a resource as highly variable as our native species. However, plantation-grown silviculturally treated stands are a completely different proposition. Inventory is more accurate, age classes are known, and crops are comparatively uniform. Pruned log quality can be predicted with reasonable accuracy when stand records have been well kept; and small numbers of sample logs, taken at maturity, may confirm or adjust predictions, or completely substitute for inadequate stand records.

In current trading, pruned log prices are still frequently based on conversion and grade outturn from one mill, and this is very often the mill with the major interest in purchasing the resource being examined. It is still common for trial truckloads to be sent to a mill for sawing to "see what happens". A slight improvement on this practice is to conduct a more controlled timber grade study on a batch of logs, usually between 30 and 100, to derive mean conversions and grade distributions – still for that mill only. With the more recent development of predictive models such as SILMOD (Whiteside & Sutton 1983) and The Radiata Pine Modelling System (Kininmonth 1987), batch study techniques for pruned sawlogs have been further improved. By implementing check grading and taking defect core measurements on a subsample (e.g., Cown *et al.* 1988) batch results may be compared to predictions from the above models and there are some options for making adjustments. However, that process remains cumbersome, results are often confusing, and the grades produced by the mill tend to remain the only result those directly involved in pruned log trading and pricing are interested in.

An aim of this paper is to show why grade and conversion results from individual mills are an inadequate basis for setting pruned log prices. The quality, and therefore potential, of pruned logs should be the most important consideration in price negotiations. This potential can be accurately determined, and isolated from sawmill variables, only by detailed analysis of individual logs. Although this is time consuming, the compensating factor is that this approach requires small sample numbers as compared to any form of batch analysis. Consequently, the total time and effort required to collect and analyse data to derive the type of results shown in this paper are usually less than required to obtain less-useful batch results.

OBJECTIVES

The objectives of this study were to:

(1) Classify and compare pruned sawlog samples;
(2) Set benchmarks for pruned sawlog conversion;
(3) Compare the recovery levels from various sawmills when converting pruned logs;
(4) Establish realistic levels for rating sawmill recoveries;
(5) Demonstrate the advantages in a standardised system of individual pruned log analysis.

DATA

Data were from 25 timber grade studies on pruned logs conducted between 1980 and 1988. Of these studies, 23 were on *Pinus radiata,* one was on *Cupressus macrocarpa,* and one was on *C. lusitanica.* Summaries of all timber grade study samples are listed in Appendix 1. Sample size for each study ranged between eight and 25 logs and the total number of logs analysed was 357. In all but two of the studies samples were selected to span the sawable diameter range available from the stand. A total of 14 sawmills were used and a range of four sawpatterns implemented.

Data on 120 logs from 11 of the above studies were prepared as input to the SEESAW simulator. This was augmented by a further 20 logs cross-sectionally analysed at three locations by the method of Somerville (1985). Combined, these provided a library of 140 pruned *P. radiata* logs from which samples could be drawn for sawing simulation exercises.

METHODS

All sawing studies were carried out by the methods of Park & Leman (1983). Conversion Potential factor (CP) and Pruned Log Index (PLI) (Park 1989a) were calculated for each log from measurements of log size, shape, and defect core size taken as a matter of routine at the time of studies. Sawing simulations to set benchmarks were carried out using the SEESAW simulator (Park 1987; Garcia 1987; Todoroki 1988).

Conversion results from each of the sawing studies and the simulations were related, using non-linear regression analysis, firstly to CP to establish levels for total conversion to sawn timber, and then to PLI to establish levels of clears grade recovery (i.e., conversion to clears grades). These clears grades ignored the effect of any resin pockets present.* PLI was also used to make direct comparisons of pruned log quality amongst study samples.

* Resin pockets are ignored in this type of analysis because, being randomly occurring defects not directly associated with pruning or basic pruned log parameters, they can confound results. They are accommodated, when "actual" results are required from individual studies, by defining their frequency (if present in significant numbers) and deriving grade reduction factors.

Upper benchmarks, against which to compare recoveries from various mills, were set by near perfect "sawing" of 61 "library" logs in the SEESAW simulator. An intention was to ensure that real mills, using current New Zealand technology and recovering timber of similar minimum and maximum dimensions, could not surpass the levels set by the simulator. "Library" logs selected for these sawing simulations ranged in length from 3 to 6 m and were chosen purely on the basis of PLI. They were selected to give an even spread across the range of PLI experienced so far in timber grade studies, i.e., PLI 1.5 to 14. The sawpattern chosen for setting the benchmarks presented here was that developed to maximise clears grades recovery during the 1986 Pruned Resource Evaluation Cooperative. This is known as the Standardised Sawpattern (STD SP) and has been fully described in a previous paper (Park 1989b). STD SP is basically a flat-sawn board pattern with a variable cant size which provides free-cutting for 25- and 40-mm-thick clears from all four faces by allowing sizing cuts, if needed, in the defect core zone (Fig. 1).

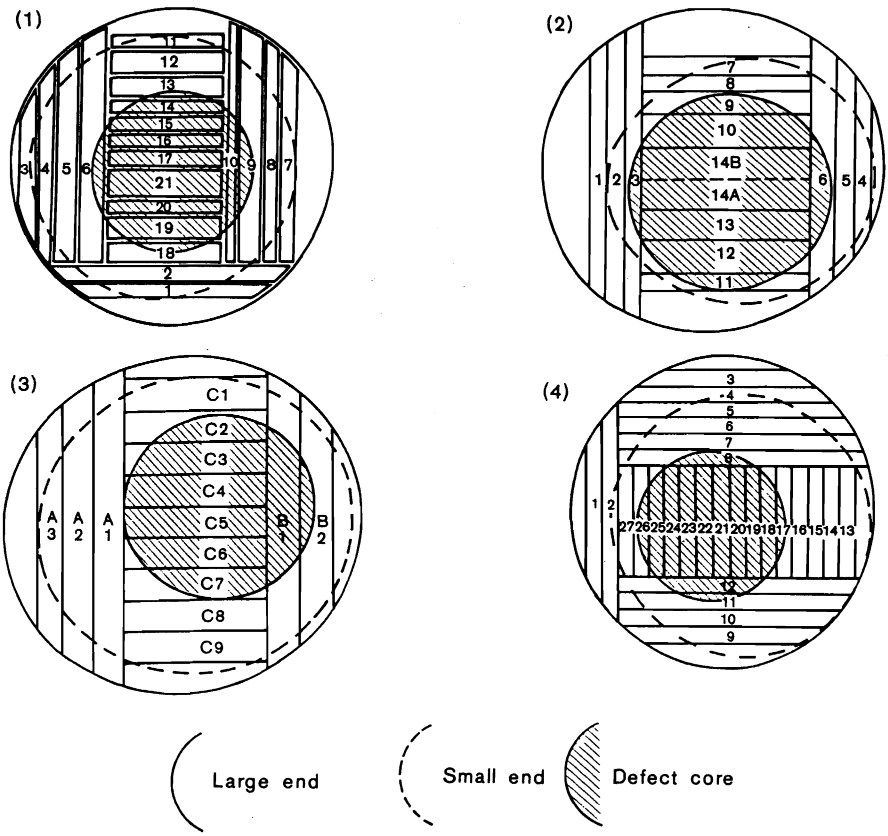

FIG. 1—Examples of sawpatterns: (1) Half-taper sawn STD SP (described in METHODS); (2) Offset sawn - cant size varies with defect core size, clears recovered in 25- and 40-mm thickness, defect core cut to 50 mm; (3) Offset sawn - fixed 200-mm cant, wing flitches cut to 40 mm by horizontal saw, cant cut to 40 mm on double arbor edger; (4) Offset sawn - cant size varies with defect core size, sawn exclusively to 25-mm thickness.

Although it was quite simple to present all results for classifying log samples by PLI it was totally impractical to attempt to present an effective appraisal of sawmill recovery levels for all 25 sawing studies. Instead, six of the studies, involving five sawmills, five batches of sample logs, and four sawpatterns plus one variation, were selected to demonstrate techniques and encompass the full range of sawmill conversion rates so far encountered. Examples of each of the four sawpatterns are given in Fig. 1. (Note: Sawpattern 1a, referred to in the results below, is identical to Sawpattern 1 in all aspects except log positioning. That mill did not have the facility to half-taper saw so the pattern was applied by offset sawing.)

RESULTS

SEESAW Simulated Benchmarks

SEESAW benchmark relationships derived for the Standardised Sawpattern are listed with estimates of goodness of fit in Table 1 and graphed, together with the plotted points, in Fig. 2 to 4. The relationship between CP and total conversion to sawn timber is shown in Fig. 2. CP ranged from 2.6 to 3.6 and across that range conversion ran from 55% to 73%. The relationship between PLI and conversion to defect-free clears is shown in Fig. 3. PLI ranged from 1.5 to 14 and across that range the percentage of log volume recovered as defect-free clears was from 0 to 56%. Recoveries in combined clears grades, i.e., defect-free clears plus clear one face, are similarly shown in Fig. 4 where percentages range from 4 to 59%.

TABLE 1–SEESAW benchmark relationships for STD SP (n = 61)

y (%)	x	Model	Coefficients a	b	c	r^2	Res.S.E.
(1) Total conversion to sawn timber	CP	$y = a + (b/x)$	120.4	−171.1	–	0.81	0.97
(2) Conversion to defect-free clears	PLI	$y = a + be^{(-cx)}$	71.54	−88.35	0.1235	0.95	0.37
(3) Conversion to combined clears grades	PLI	$y = a + be^{(-cx)}$	64.00	−74.54	0.2037	0.92	0.41

CP = Conversion Potential factor
PLI = Pruned Log Index
Combined clears grades = defect-free clears + clear one face

The curves for defect-free clears and combined clears grades are plotted together in Fig. 5 to give the reader an appreciation of their relationship to each other. In order to simplify, all following results on clearwood conversion rates are represented by combined clears grades only.

Classification of Pruned Log Samples

Results from the benchmarking exercise were used to provide an interpretation of what PLI values mean and derive broader classes for pruned log quality. This was done

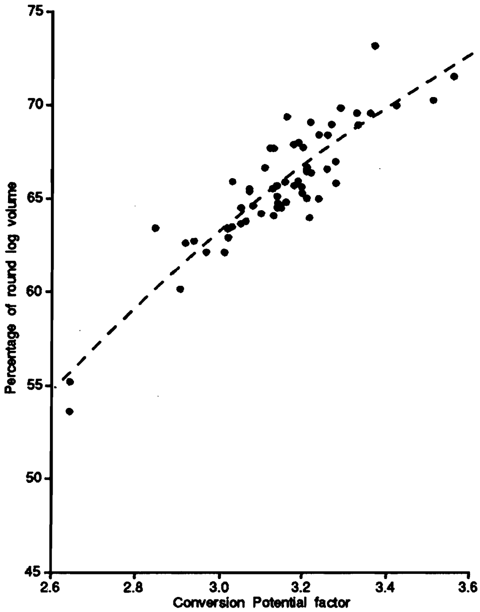

FIG. 2—STD SP benchmark relationship for total conversion to sawn timber.

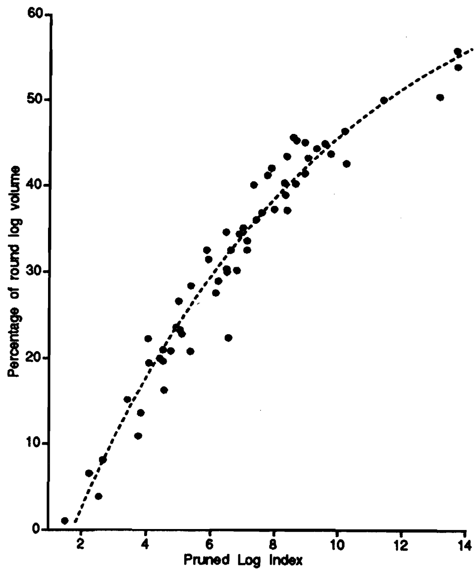

FIG. 3—STD SP benchmark relationship for conversion to defect-clears.

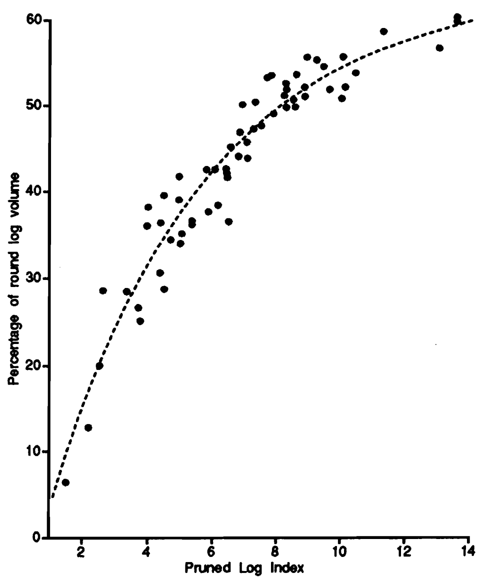

FIG. 4—STD SP benchmark relationship for conversion to combined clears grades.

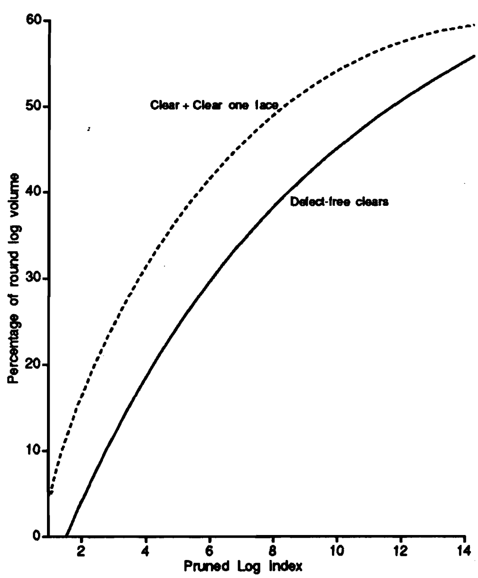

FIG. 5—STD SP benchmark relationship for conversion to clears grades.

by dividing the PLI range as shown in Fig. 6. The purpose was to simplify the ranking and comparison of pruned log samples and provide a perspective on the range of pruned log types currently available in New Zealand. This is demonstrated in Fig. 7 where 25 batches of pruned log samples from previous sawing studies are ranked in ascending order of PLI classes. Summarised details of each set are given in Appendix 1. In all but

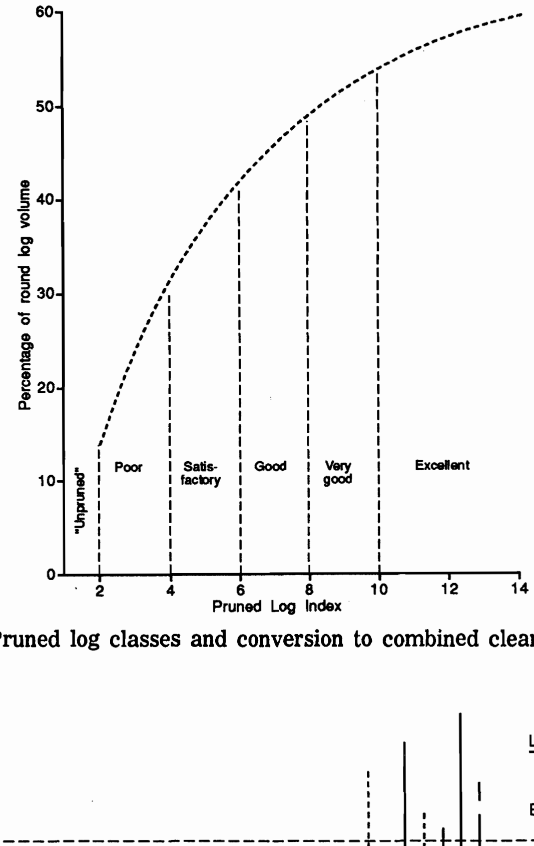

FIG. 6—Pruned log classes and conversion to combined clears grades.

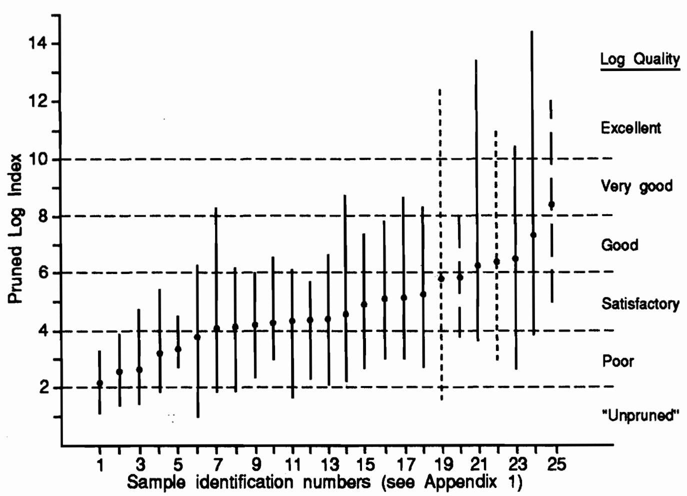

FIG. 7—Range and means of pruned log indices from 25 sawing studies (sample 19 is **C. macrocarpa**, 22 is **C. lusitanica**, 20 is mid-diameter logs only, and 25 is the top end of the range available).

two batches these samples were selected to span the sawable diameter range of pruned logs available in the parent stand. Sample Sets 20 and 25 have been differentiated in Fig. 7 because Set 20 comprised mid-diameter logs only and Set 25 represented only the top end of the range available. Further differentiation is made on Sets 19 and 22 to identify them as cypresses: Set 19 are *C. macrocarpa* and Set 22 *C. lusitanica.* Interest is not only in the means but also in the range spanned by each sample set; therefore both have been presented.

Comparison of Sawmill Recoveries

Sawmill recoveries, in the context here, refer only to levels of total conversion to sawn timber and clears grade recovery. Relationships derived from five sawmills for total conversion and conversion to combined clears grades are listed in Appendix 2. These are plotted, together with the simulation benchmarks in Fig. 8 and 9. They represent the full range, from best to worst, of results found from 25 timber grade studies. This range of results has been used to calibrate and qualify sawmill recoveries against the benchmarks established using SEESAW (Fig. 10). A good result for a real mill is to come within 5% of benchmark levels, within 10% is satisfactory, within 15% is substandard, and below 15% is poor. Using these criteria, the mill recoveries (Fig. 8 and 9) are further classified and compared in Table 2. The table simplifies comparison and identifies the following points of interest.

(i) None of the mills paralleled both the conversion and clears grade recovery benchmarks across the range of logs they sawed, i.e., they did not stay within one performance class for both types of conversion (recoveries from various mills peaked in differing parts of the range – *see also* Fig. 8 and 9).

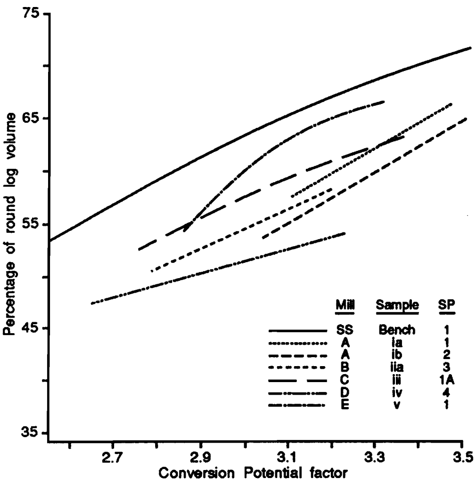

FIG. 8—Comparison of total timber recovery.

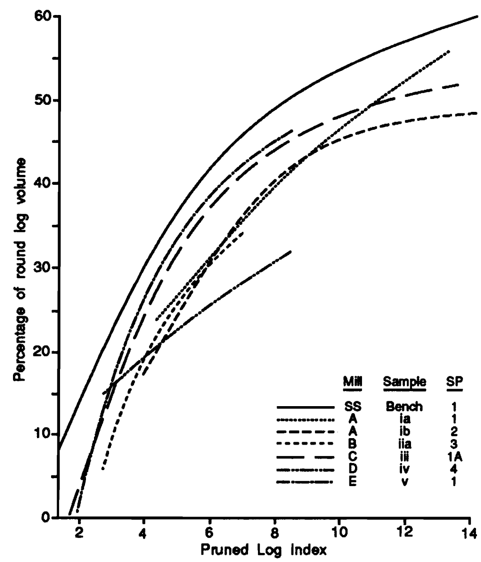

FIG. 9—Comparison of recoveries in combined clears grades.

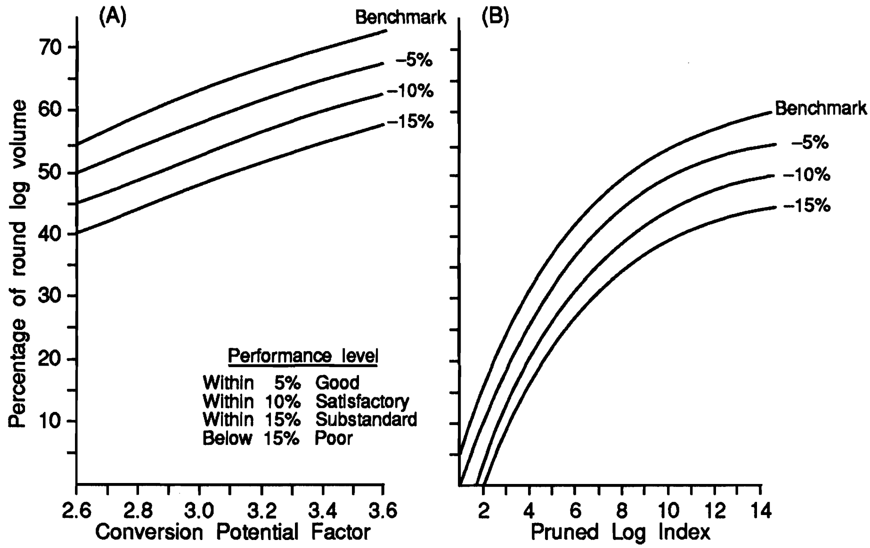

FIG. 10—Sawmill performance levels for pruned log conversion: (A) Total conversion to sawn timber; (B) Conversion to combined clears grades.

TABLE 2–Comparison of conversions from five sawmills

Mill	Sawpattern	Conversion to ...	
		Total sawn timber	Combined clears grades
A	1	Satisfactory/good	Satisfactory/good
A	2	Satisfactory	Substandard/satisfactory
B	3	Satisfactory	Poor/substandard
C	1a	Satisfactory	Satisfactory/good
D	4	Satisfactory/substandard/poor	Satisfactory/substandard/poor
E	1	Satisfactory/good	Good

Good = within 5% of SEESAW benchmark
Satisfactory = within 10% of SEESAW benchmark
Substandard = within 15% of SEESAW benchmark
Poor = more than 15% below SEESAW benchmark

(ii) Sawmill E achieved the best result using Sawpattern 1 (STD SP) with satisfactory/good conversions and good clears grades recovery.

(iii) The second-best recoveries, satisfactory/good, for both total sawn timber and clears grades, were from Mill A which also implemented Sawpattern 1.

(iv) Conversions from Sawmill A, using Sawpattern 2 on samples matched to those sawn in the same mill under Sawpattern 1, dropped to satisfactory and clears grades recovery dropped even further to substandard/satisfactory.

(v) Conversions from Mill A using Sawpattern 2 and Mills B and C were all satisfactory but clears grades recovery ranged from poor/substandard to satisfactory/good. This demonstrates how substantially clears recovery can vary under one conversion rate to total sawn timber. While good clears recovery cannot be achieved from poor conversions, a satisfactory or good conversion rate does not automatically ensure equivalent clears grades recovery. Other factors such as sawpattern and breakdown and edging techniques may also exert a strong influence. It is also worth noting that the best clears recovery performance of these three mills, Mill C satisfactory/good, was achieved with Sawpattern 1a, a variation on the STD SP.

(vi) The worst performance was from Mill D. While this was basically poor it ranged, for both conversion and clears recovery, from satisfactory on the worst logs it sawed through to substandard and then poor as logs improved (*see* Fig. 8 and 9). At PLI 8.5 clears grades recovery was 14 percentage points below the best-performed mill, Sawmill E, and 18 percentage points below the benchmark.

DISCUSSION

The benchmarks set here, using the SEESAW simulator, should provide a better perspective on sawing results than has previously been available. For simplicity, analyses of real sawing results were limited to total conversion and recovery in combined clears grades. However, a benchmark was also presented for recovery of defect-free clears alone because, in some circumstances, this may be the result of major interest. Although the three benchmarks are directly applicable to most current New Zealand sawmilling situations they should not be used out of context. They should be regarded as usable examples of this technique rather than the absolute upper limit of possible sawmill conversion rates. They do not, for example, apply to some of the Japanese sawing techniques which are known to produce results well above these benchmarks for a range of seasons (e.g., smaller sawkerfs, much greater flexibility in recoverable sizes). Similarly, the benchmarks given were all based on cutting for 25- and 40-mm boards and some New Zealand mills could surpass the benchmark presented for total conversion to sawn timber by cutting the centres of logs to large dimensions. This, however, is not a limitation. New SEESAW benchmarks are easily derived for any defined sawing system.

The log sample and sawmill analyses presented here drew on 25 timber grade studies conducted since 1980. This collation was possible, firstly, because information was gathered on individual logs (as opposed to batch means), and, secondly, because there has been a standardised system over that period. Data collected by the timber grade study method of Park & Leman (1983) has always been durable and directly comparable. Since the development of SEESAW there is the added benefit of the ability to remove sawmill variables. The subsequent development of the indices CP and PLI provide for rapid unbiased comparisons and interpretations of timber grade study data. They also provide an easy path for relating real results to results from SEESAW simulations. Results here have also demonstrated how PLI is independent of log length and can be used effectively on species other than *Pinus radiata.*

Comparison of the 25 sample sets (Fig. 7) shows the range of pruned log quality currently available to New Zealand sawmillers. As yet there are very few well-pruned logs that have reached maturity and the distribution shown in Fig. 7 fairly well reflects that of the current "transition crop". The bulk of samples fall in or close to the satisfactory class. More recent pruning on crops still maturing is expected to result in greater representation in the good and very good classes. Another observation is that as the mean PLI increase the range of log quality (or PLI) expands, i.e., as stands improve, the difference between the best and the worst pruned logs becomes greater. This trend is to be expected and has a simple logical explanation. When pruning is model, trees are pruned hard at an early age and the resulting defect cores are small and comparatively uniform. However, no matter what further silviculture may follow, crops inevitably revert to an approximately normal distribution of tree sizes at rotation age, with the difference between diameters of the larger and the smaller pruned logs being anything from 15 to > 50 cm (see Samples 16 to 25 in Appendix 1) depending on a range of factors such as planting stock, site uniformity, regularity of spacing, final-crop stocking, and rotation length. Thus, a range of clearwood sheaths may be laid down over defect cores which are all of a similar size. It follows that within a given pruned stand there is a relationship between pruned log size and quality and this has been confirmed by all studies summarised in Appendix 1. Therefore, while the mean PLI of logs sampled across the diameter range may establish over-all pruned sawlog quality and provide for direct comparisons between stands, it may not be sufficient on its own. The range is also important and when the stand average pruned log quality is found to be good, it is prudent to generate separate means for the small element, the midsize logs, and the large element (e.g., Somerville *et al.* in prep.).

Comparisons of mill recoveries (Fig. 8 and 9, and Table 2) confirmed firstly that large differences can occur between mills and secondly that the Standardised Sawpattern (STD SP) was the most effective. The three best recoveries were achieved when mills implemented this sawpattern.

In the past there have been disputes between millers and suppliers about the quality of pruned logs, and these are expected to flare from time to time in the future. Previously there was no satisfactory means of resolving such arguments but the techniques shown here make this quite straightforward. When a mill is dissatisfied with its recoveries from a line of pruned logs a small study on 10 to 15 logs spanning the diameter range will resolve the problem. Log quality is standardised and defined by PLI and mill recoveries are gauged against the SEESAW benchmarks and/or other sawmills. There are only three possible eventualities – the logs are below specification, the mill is not converting the logs satisfactorily, or both log quality and mill performance are below expectation. These methods have already been effectively employed in a dispute between a large sawmill and a major grower.

Finally, the range of mill recoveries (Fig. 8 and 9) shows how inequitable a system of fixing log prices from mill output could become. Those results were all obtained under controlled study conditions and consequently the worst result, from Mill D, is far from being the worst probable. Some mills currently operating in this country are not expected to be competitive with any of these results when operating at normal production speed. Pruned log prices based on mill output are biased not only against the log seller, but also against the better suited mills. These mills are likely to be penalised for good performance during sawing trials by eventually having to pay more for equivalent logs than their less proficient competitors.

ACKNOWLEDGMENT

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APPENDIX 1

PLI RANGE AND MEANS FROM SAWING STUDIES

Forest	Cpt	Sawmill	Study date	Stand		No. of logs	Log length (m)	s.e.d. (mm)		PLI	
				Age (yr)	Stems/ha			Range	Mean	Range	Mean
1. Golden Downs	95	Donnelly's	1981	25	950	15	4.9–5.5	273–353	308	1.15–3.32	2.22
2. Aupouri	3/2	Kaitaia	1983	18	275	13	5.2–5.5	244–341	284	1.45–3.93	2.61
3. Mangatu	1	TITC	1981	21	335	12	5.5	204–445	348	1.38–4.74	2.71
4. Aupouri	11/3	Kaitaia	1983	16	245	15	4.9–5.5	201–357	293	1.89–5.46	3.25
5. Golden Downs	116	Donnelly's	1981	22	345	15	5.5	290–382	319	2.76–4.49	3.43
6. Santoft	Pop. 1	Bulls	1985	28–29	280–360	12	5.5	307–494	376	1.01–5.94	3.81
7. (Confidential)			1988	37	242	15	5.5	290–507	374	1.92–8.30	4.11
8. Te Wera	23/04 (Waverley)	Bell Block	1983	28	542	8	5.5	298–572	430	1.95–6.20	4.19
9. Te Wera	1201	Bell Block	1983	26	831	8	5.5	270–533	402	2.37–6.01	4.25
10. Waiuku	35	Aitkenhead (Pokeno)	1981	27	246	10	5.5	390–524	428	3.00–6.54	4.33
11. Rankleburn	502	JACS (Balclutha)	1988	34	545	10	4.9–5.2	250–487	368	1.68–6.11	4.34
12. Kaingaroa (Trial R347)	1318	TITC	1980	17	185	12	5.5	246–400	323	2.39–5.75	4.40
13. Santoft	Pop. 2	Bulls	1985	24–26	224–417	12	5.5	308–520	396	2.15–6.69	4.43
14. Waitangi	6/1	Waitangi	1981	27	195	14	5.5	307–612	440	2.24–8.76	4.53
15. (Confidential)			1987	28	400?	19	4.9	316–469	399	2.70–7.30	4.93
16. Herbert (Balclutha)	21	Rosebank Davies	1981	26	308	15	5.5	302–437	367	3.07–7.77	5.11
17. Patunamu	3	TITC	1981	28	123	13	5.5	313–551	409	2.51–8.61	5.15
18. Rankleburn (Balclutha)	5	Rosebank Davies	1981	26	288	15	4.9–5.5	296–439	366	2.68–8.27	5.22
19. Hulls Woodlot	(*C. macrocarpa*)	TITC	1986	52	415	25	3.7–5.5	208–730	435	1.63–12.29	5.79
20. (Confidential)	Mid dbh logs (4 compartments)		1986	25–31	150–167	20	3.7–6.1	416–517	468	3.80–7.94	5.83
21. Rankleburn	505	JACS	1988	33	392	15	4.9–5.5	296–439	366	2.68–8.27	5.22
22. Tairua	(*C. lusitanica*)	Thames	1988	58	371	13	3.7–6.1	293–787	493	2.98–10.88	6.35
23. Te Wera	23/05	Bell Block	1983	28	107	9	5.5	341–626	487	2.65–10.35	6.40
24. (Confidential)	(Shorts)		1987	31	Unknown	20	2.5–4.1	341–598	469	3.89–14.35	7.27
25. Ngaumu (Trial WN227)	Biggest trees	Otope	1988	32	200–250	22	3.9–5.9	411–595	520	4.94–11.88	8.33

APPENDIX 2

CONVERSION RELATIONSHIPS FOUND IN FIVE SAWMILLS UNDER CONTROLLED TIMBER GRADE STUDY CONDITIONS

Mill	Sawpattern	Sample	n	Range	Model	Coefficients			r^2	Res.SE
						a	b	c		
y = conversion (%) to total sawn timber; X = CP										
A	1	ia	10	(3.10–3.46)	$y = a + bx$	–15.85	23.67		0.67	0.79
A	2	ib	10	(3.03–3.50)	$y = a + bx$	–20.26	24.31		0.58	1.03
B	3	ii	10	(2.79–3.21)	$y = a + bx$	–1.053	18.52		0.41	1.02
C	1a	iii	25	(2.74–3.35)	$y = a + b/x$	111.8	–162.7		0.47	0.69
D	4	iv	14	(2.65–3.23)	$y = a + bx$	17.24	11.38		0.37	0.74
E	1	v	15	(2.85–3.31)	$y = a + bx + cx^2$	–464.8	316.4	–47.11	0.72	0.74
y = conversion (%) to defect-free clears; X = PLI										
A	1	ia	10	(4.3–13.0)	$y = a + be^{-cx}$	61.27	–104.5	0.1548	0.93	1.44
A	2	ib	10	(3.9–14.4)	$y = a/(1 + EXP(b - cx))$	41.57	4.129	0.6171	0.90	1.82
B	3	ii	10	(2.7–6.9)	$y = a/(1 + EXP(b - cx))$	63.76	4.377	0.6097	0.82	1.66
C	1a	iii	25	(1.7–13.4)	$y = a + be^{-cx}$	60.22	–73.82	0.1116	0.83	1.00
D	4	iv	14	(2.7–8.3)	$y = a + bx$	–1.092	3.333		0.60	1.20
E	1	v	15	(1.9–8.3)	$y = a + bx$	–8.977	4.774		0.93	0.61
y = conversion (%) to combined clears grades; X = PLI										
A	1	ia	10	(4.3–13.0)	$y = a + be^{-cx}$	91.48	–92.67	0.07317	0.85	1.73
A	2	ib	10	(3.9–14.4)	$y = a/(1 + EXP(b - cx))$	48.66	2.719	0.5457	0.68	3.14
B	3	ii	10	(2.7–6.9)	$y = a + be^{-cx}$	41.09	–98.45	0.3807	0.74	2.28
C	1a	iii	25	(1.7–13.4)	$y = a + be^{-cx}$	53.75	–86.08	0.2788	0.89	0.98
D	4	iv	14	(2.7–8.3)	$y = a + bx + cx^2$	4.269	4.286	–0.1153	0.63	1.08
E	1	v	15	(1.9–8.3)	$y = a + be^{-cx}$	51.23	–100.8	0.3542	0.71	1.70