PRUNED LOG INDEX

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ABSTRACT

A Pruned Log Index (PLI), derived from measurements of log size and shape and the size of the defect core, has been developed as an absolute measure of pruned sawlog quality. It is based entirely on measurable log variables routinely acquired under either of two established pruned log analysis systems. Being dependent on accurate and detailed measurements, PLI is of higher precision than other existing forms of pruned log classification. Consequently its application should be limited to real logs only (other less precise measures are more appropriate for predicting future log quality).

The index was developed and validated with the assistance of the pruned log sawing simulator SEESAW. Simulation was used in preference to the real sawing results available in order to avoid the confounding influences of sawmill variables. This simulation approach also allowed the performance of trial formulae to be examined under three distinct sawing systems. Initial derivation of formulae was intuitive, based on previous experience, and all formulae included terms for log size, log shape, and defect core size. Trial indices were regressed against conversions to clears grades from SEESAW simulations using two sets of real log data from the SEESAW "library". Set 1 consisted of 74 pruned **Pinus radiata** D. Don logs, originally acquired through sawing studies, and was used to explore and evaluate trial formulae. Set 2 consisted of 15 logs, originally acquired through log cross-sectional analysis, and was used for validation.

Keywords: pruned sawlogs; log quality; sawing simulation; SEESAW; grade recovery.

INTRODUCTION

The major reason for pruning in New Zealand is to produce clearwood. The practice of pruning for clearwood has steadily increased since the 1940s; for example, on State plantations an average of 2718 ha per annum were pruned during the 1940s and this rose to an average of 56 139 ha per annum over the first 5 years of this decade. Stands pruned during the late 1940s, the 1950s, and the early 1960s, collectively known as the "transition crop" are now being harvested. As predicted by Park (1980), and reiterated more recently by Somerville *et al.* (1985), most parties involved in the trading and utilisation of pruned logs have come to recognise the need to evaluate the pruned components of stands before prices are negotiated. They also now appreciate that pruned log quality cannot be determined from external appearance alone. Internal assessment is an essential complement. To date, all efforts at predicting the internal characteristics of pruned logs in existing mature stands have proved inadequate, largely because stand histories and silvicultural records for the "transition crop" are either inadequate, inaccurate, or non-existent. At present, the only means of acquiring the necessary information on pruned logs prior to clearfelling is to dissect a number of sample logs. There are two established methods for doing this – the sawing study method of Park & Leman (1983), and the cross-sectional analysis system of Somerville (1985).

In 1986 a ". . . Pruned Log Evaluation Cooperative was jointly funded by industry and the FRI. In its 1-year brief it set out to evolve and further develop systems for describing and evaluating pruned radiata pine logs" (Somerville *et al.* in prep.). Objectives concerning pruned sawlogs included standardising methods of analysis and expressions of quality. Efforts centred on defining the potential of pruned sawlogs to yield clear grades. This potential yield is distinct from the results that might be achieved in actual sawing, although this was not ignored. The large family of multiple regressions in SAWMOD (Whiteside & McGregor 1987) remain useful for predicting grade outturn and value under three sawpatterns and four conversion standards in eight mill types. However, the pruned log sawing simulator SEESAW (Park 1987; Garcia 1987; Todoroki 1988) was identified as the most appropriate tool for interpreting pruned sawlog potential because it permits the total isolation and control of mill variables, and options for varying the sawpatterns, conversion standards, and mill types are virtually unlimited. Even when most of the variation that inevitably occurs during the sawing process is removed by using the SEESAW simulator, results still depend on the choice of sawmill variables and sawpattern. The most desirable measure of pruned sawlog quality is one which is highly correlated to sawing results but is derived from log characteristics alone and therefore independent of the sawing process itself.

Deriving such a measure was difficult before the development of the SEESAW simulator because the database consisted of real sawing results only and the influences of the sawmills used could never be totally identified let alone isolated.

This paper reports the development of a Pruned Log Index and discusses some of its applications.

Previous Pruned Sawlog Indices

The concept of indexing pruned sawlogs is not new and two forms were developed at FRI prior to the development of SEESAW.

Grade Index (Park 1980) = (dbh/defect core) × conversion

Grade Index remains useful as a long-term predictor of expected log quality, but it is not appropriate to the purpose here because the formula includes conversion. The "catch-all" conversion variable in the Grade Index formula is either real or assumed and is surrogate for a mixture of external log variables (e.g., sweep, crook, ovality, and taper) and all the sawmill variables. However, the expression of knotty core size and shape initially derived for Grade Index, viz defect core, remains very useful to this purpose. 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).

Since 1980, all equations and models developed at FRI for predicting clears grade timber "off the saw" have incorporated the term defect core.

Pruned log stand quality classification (Whiteside & Manley 1987)

This is a simple and effective method of grouping pruned stands by the mean clearwood sheath value found, i.e., small-end diameter (s.e.d.) – defect core. Stands are grouped into five classes by 50-mm increments of s.e.d. – defect core. It has the advantage that it is independent of processing variables but the disadvantage that all external log features are represented by only one very simple expression of size. This shortcoming renders clearwood sheath inappropriate for any individual log analyses.

OBJECTIVES

The prime objective of this study was:

> *To derive an index, based entirely on measurable log variables, to express and reflect pruned sawlog potential for producing clears grade timber "off the saw" (i.e., without grade enhancement by docking or defecting).*

This objective was to be addressed using real log data and simulated sawing in SEESAW in order to hold all sawmill variables constant. "Measurable log variables" were defined as those data routinely collected under the sawing study method of Park & Leman (1983) and the cross-sectional analysis system of Somerville (1985).

The proposed functions of such a pruned sawlog index were to:

(a) Rank pruned logs by their potential to produce sawn clearwood;

(b) Provide for direct comparisons across all pruned sawlog types;

(c) Provide a reliable statistic on which to base stand quality when carrying out pruned resource evaluation;

(d) Provide a rationale for log selection in SEESAW simulation exercises;

(e) Provide a standard method of presenting results from sawing studies of actual logs, simulated sawings, and predictions of clears grade recovery from measurements taken on actual logs.

As over-all conversion to sawn timber has been shown to directly affect conversion to clear grades (Park 1980) the prime objective was redefined as a two-stage study to explain and predict:

(1) Total conversion to sawn timber using a combination of external log variables;

(2) Conversion to clears grade timber by deriving an index based on the result of (1) and measurements of defect core.

DATA

Data were in two sets. Set 1 consisted of 74 pruned butt logs "reconstructed" from past sawing studies, and represented a range of log sizes and silvicultural regimes from four sites in the South Island and two sites in the North Island. The original selection

TABLE 1–Summary of sample logs

Location of sample point	No. of logs	Age (yr)	No. of pruning lifts	Final-crop stocking (stems/ha)	Range of ... Log size (dia. at 1.3 m (ub)) (mm)	Defect core size (mm)	Sweep (max. displ. at mid log) (mm)	Taper index (mm/m)
DATA SET 1 (Derived from sawing studies)								
Ranklebum Cpt 5	13	26	2	288	328–542	190–287	15–58	8–32
Herbert Cpt 21	14	26	3	308	348–504	188–304	11–48	3–32
Golden Downs Cpt 95	12	25	3	950	294–386	213–270	8–58	3–11
Golden Downs Cpt 116	11	22	3	345	324–376	173–234	8–50	7–11
Patunamu Cpt 3	14	28	2	123	364–558	205–297	7–60	7–23
Mangatu Cpt 1	10	21	2	335	376–482	220–343	7–54	6–16
	74	21–28	2&3	123–950	294–558	173–343	7–60	3–32
DATA SET 2 (Derived from cross-sectional analysis)								
Ngaumu (various*)	5	28–29	2	200–380	400–542	239–323	30–84	4–15
Rai Valley Cpt 9	5	32	2	296	400–572	315–372	29–71	6–15
NZFP (Woutu Block)	5	32	3	253	394–604	249–332	15–67	8–17
	15	28–32	2&3	200–380	394–604	239–372	15–84	4–17

* Logs were selected from a stratum comprising six stands.
Note: Log lengths are all either 4.9 m or 5.5 m.

criteria for these logs were that they were well pruned, nominally straight, and aged between 20 and 30 years. Set 2 was compiled, for validation purposes, by selecting 15 pruned logs from data collected by cross-sectional analysis. These logs represented three types of silviculture, were drawn from two sites in the North Island and one site in the South Island, and had been selected randomly. Summaries of the six subsets comprising Data Set 1 and the three subsets comprising Data Set 2 are given in Table 1. The geographic locations of all sample points are shown in Fig. 1.

The differences between Set 1 and Set 2 were quite major. On average, logs from Set 2 were older, larger, less tapered, more swept, and had bigger defect cores than those from Set 1 (Table 1).

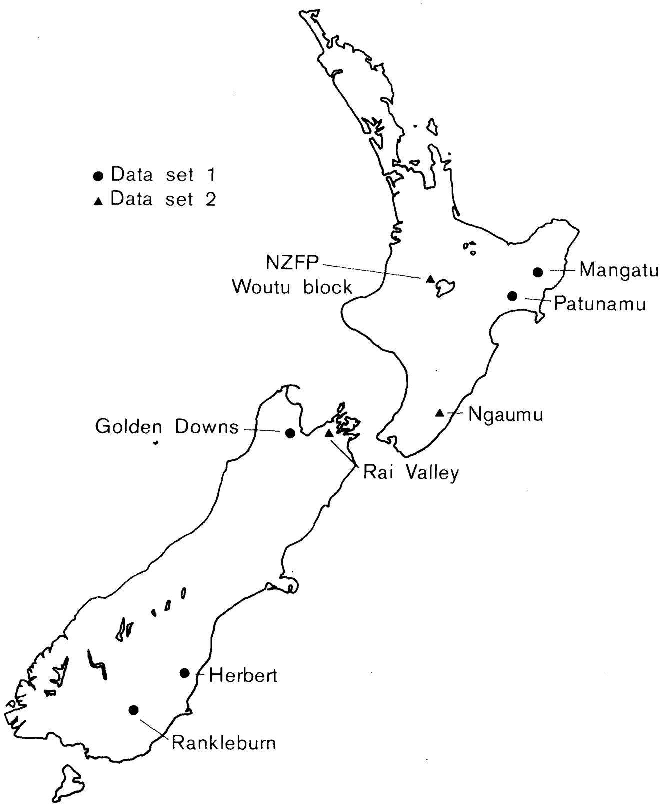

FIG. 1—Location of log sampling sites.

METHODS

Sawing Simulations

All samples from both data sets were "sawn" under three different sawing systems (Fig. 2). These were:

(1) Cant sawing with natural offset;
(2) Half-taper cant sawing;
(3) Half-taper live sawing.

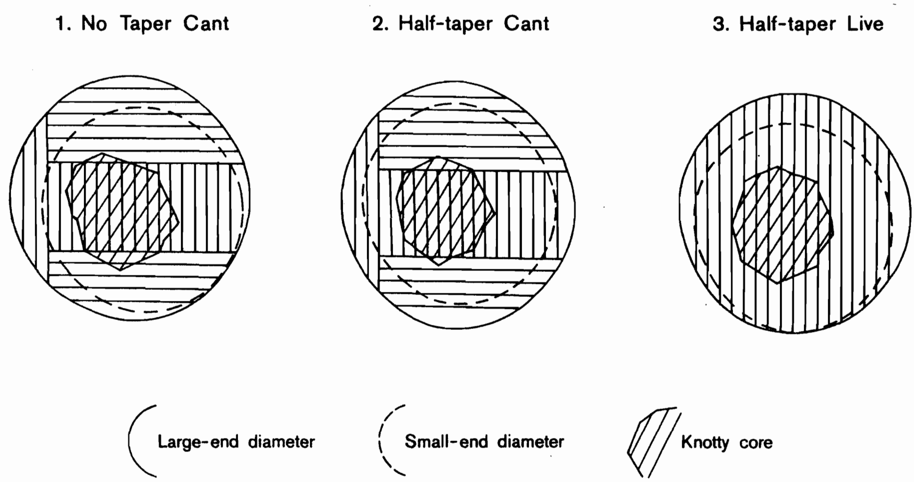

FIG. 2—Examples, using Log 658, of the three sawing systems used.

For all simulations, a three-knee carriage was defined and sawkerfs were set at 3 mm for the headrig and 6 mm for edging. The same procedure was used for all log types and each of the sawing systems. Wing flitches were cut to the minimum recoverable thickness of 25 mm and were edged for grade. Recoverable widths were set at 50, 75, 100, 150, 200, 250, and 300 mm.

The cants produced from sawing systems (1) and (2) were also sawn to 25 mm and complete boards from these cants were not further edged to improve grade. Cant sizes varied with defect core sizes and the range of allowable cant depths was set at 100, 150, 200, and 300 mm.

Data Analyses

Conversion Potential factor (CP)

A parameter which could be used to predict total sawn timber conversion was developed. The log variables important to conversion, most simply stated, are size and shape.

The most commonly used expression of log size is small-end diameter under bark (s.e.d.) but this has the limitation that it is dependent on log length and, in pruned butt logs, is often affected by nodal swelling from the base of the first whorl of unpruned branches. In order to examine other options for expressing log size, all 5.5-m logs were extracted from Set 1. These totalled 62 and were used to determine how well the square of under bark diameters from various positions up the log related to log volume for a constant log length. Results (Table 2) showed that diameters 1.3 m and 2.6 m from the butt end were best related to log volume. Diameter at 1.3 m (D 1.3) was chosen in preference to diameter at 2.6 m because, in butt logs, it is virtually the same point as dbh when the tree is standing. A further advantage in adopting D 1.3 is that it is common to pruned sawlogs of all lengths.

TABLE 2–Relationship between diameter squared and volume of 5.5-m-long pruned *Pinus radiata* butt logs

Model y = a + bx   y = volume (m^3)   x = under bark diameter^2 (mm)
n = 62
(range of y = 0.361 m^3 –1.093 m^3)

x DIAMETER POSITION (distance from butt)	a	b	r^2	S.E.Res.
D_0^2 (l.e.d.)	0.617E-01	0.282E-05	0.926	0.707E-02
$D_{1.3}^2$	0.260E-01	0.390E-05	0.985	0.308E-02
$D_{2.6}^2$	0.168E-01	0.436E-05	0.985	0.949E-03
$D_{3.9}^2$	–0.850E-02	0.490E-05	0.981	0.339E-02
$D_{4.9}^2$	–0.742E-02	0.511E-05	0.959	0.505E-02
$D_{5.5}^2$ (s.e.d.)	0.161E-01	0.500E-05	0.937	0.624E-02

The main components of log shape are sweep, crook, taper, and ovality.

Rather than considering log shape by its various components, it was decided to collectively express all of these using a new concept, that of the volume of wood common to the whole log. Using this concept a log can be reduced to two basic components – wood which is common to the whole length of the log and wood which is not. Initially, common wood was defined as the largest complete cylinder available but this was discarded as being more relevant to the peeling process (one severe indentation can drastically reduce the size of such a cylinder but may have little effect on sawn recovery as it affects only one face of the log). The expression of common volume found to be most appropriate for sawlogs was the column calculated from four quarter ellipses. The semi-axes for these ellipses are the minimum radii measured from the central or Z axis of a log in both the X and Y planes (Fig. 3). To accommodate differences in shape among logs of the same size, the volume of common wood (CVOL) was expressed as a percentage of total log volume.

Pruned Log Index

Data Set 1 was used to derive formulae that might satisfy the objectives stated earlier and also be applicable to each of the sawing systems used. This was initailly an intuitive process founded on the author's previous experience. Cognisance was also taken of the range of variables and terms successfully employed by others at FRI to predict conversions and clears grades using multiple regressions (e.g., Whiteside 1982; Cown *et al.* 1987).

Trial formulae derived from log variables were regressed against results from the sawing simulations using a modification of the Gauss-Newton method of non-linear regression analysis (Hartley 1961). A total of 23 formulae were tested as predictors of conversion to clears grade timber (i.e., the percentage of round log volume obtained in clear and clear one face grades). The performance of each index derived was determined by examining goodness of fit on Set 1 then superimposing curves modelled from Set 1 over the plotted points of Set 2. Models finally chosen from those of good fit on Set 1 were those which were also judged to best fit Set 2.

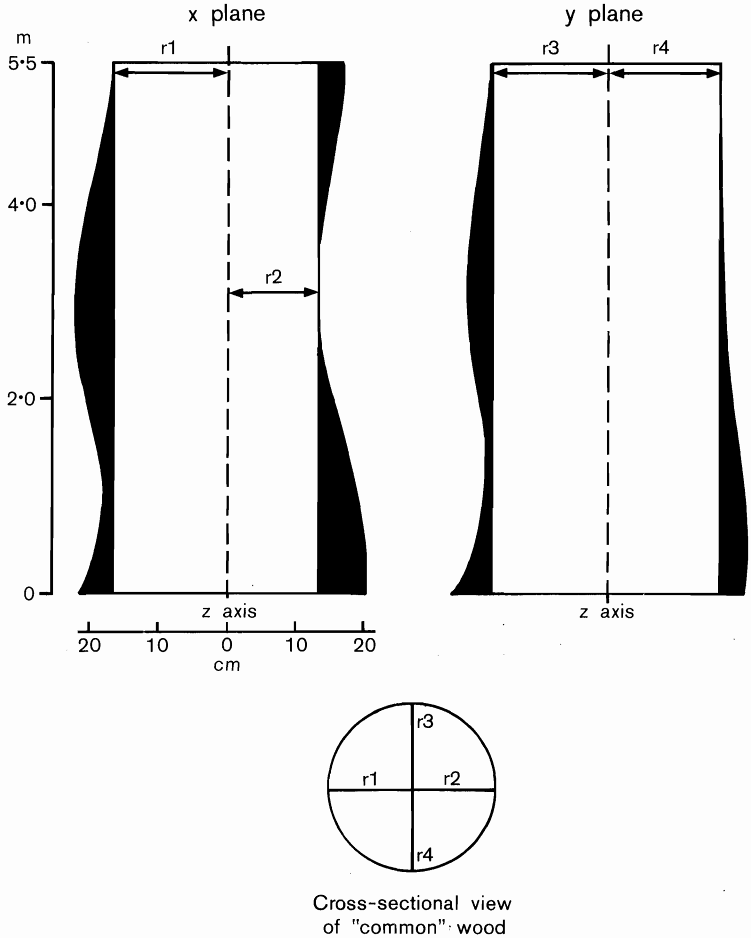

FIG. 3—Illustration of "common volume" using Log 907. CVOL is defined as the column of wood common to the whole log length with a cross-section derived from four quarter ellipses. The semi-axes for these ellipses are the minimum radii measured from the central or Z axis in both the X and Y planes.

RESULTS

Results were similar for each of the three sawpatterns used and this resolved the concern that the indices might not have been suitable for all sawing methods. In the interests of simplicity, results from the half-taper sawing only are given here. A comparison of the three sawing systems, which also shows an application of formulae derived here, is given by Park (1989a).

Conversion Potential Factor

By combining common volume percentage with the chosen expression of log size (D 1.3) a factor to express the conversion potential of sawlogs of all sizes was derived as follows:

$$\text{Conversion Potential (CP)} = (D\,1.3)^{0.2} \times \left(\frac{\text{CVOL}}{\text{LVOL}}\right)^{0.5}$$

where D 1.3 = diameter (mm) under bark 1.3 m from the butt end of logs
CVOL = volume of common wood (m^3)
LVOL = under bark log volume (m^3).

The relationship between CP and conversion from Set 1 is given in Table 3 and shown in Fig. 4a. While an asymptotic curve is more logical, a straight line gave the best fit over the range of data available (log size would need to approach 2 m in diameter before the upper asymptote would be approached). The fit of the Set 1 line over plotted points from Set 2 is shown in Fig. 4b. Although the upper range of data

TABLE 3–Models adopted for half-taper sawing of Data Set 1 (n = 74)

X	Y (% of round log)	Model	a	b	c	r^2	S.E.Res.
CP	Total conversion	$y = a + bx$	1.743	20.79		0.81	0.17
PLI	Defect-free clears	$y = a + be^{-cx}$	98.63	−109.3	0.0800	0.89	0.41
PLI	Combined clears grades (clear + clear 1 face)	$y = a + be^{-cx}$	70.41	−76.12	0.1450	0.89	0.40

CP = Conversion potential factor.
PLI = Pruned Log Index.
Note: Equations derived from *combined* data sets for offset, half-taper, and live sawing are given by Park (1989b).

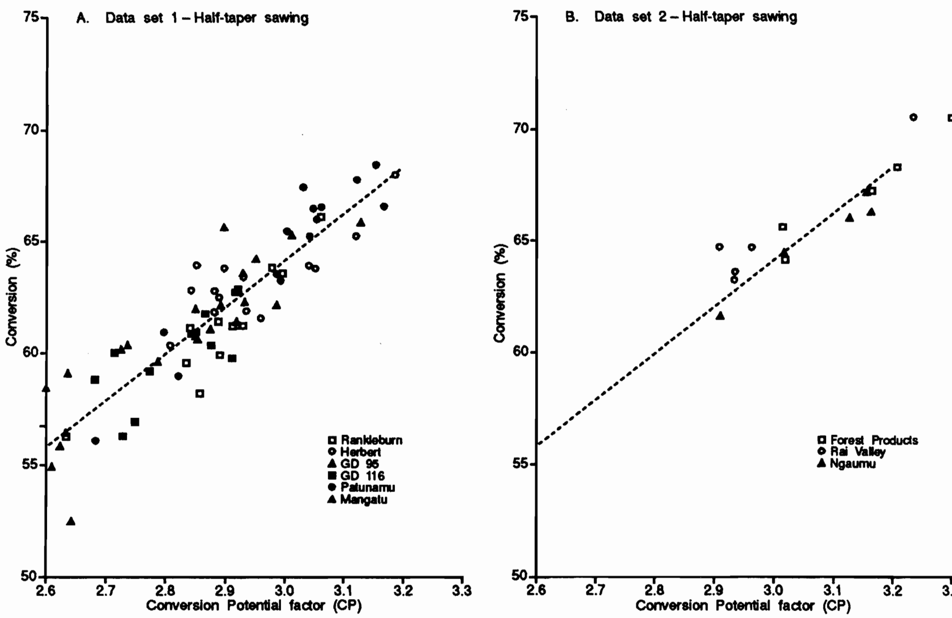

FIG. 4—Relationship between Conversion Potential factor (CP) and total conversion to sawn timber from half-taper sawing of Data Set 1 only;
(a) fitted on data points from Set 1;
(b) superimposed over data points from Set 2.

in Set 2 exceeds that of Set 1 (due to larger log size) the line derived from Set 1 is equally appropriate to both Sets.

Pruned Log Index (PLI)

Twenty-three indices were derived and tested for predicting conversion to clears grades. All included variations of three basic parameters defined for log size, log shape, and defect core size. Log size was expressed as D 1.3. Log shape was accommodated by the ratio of common volume to log volume. However, the definition of defect core, given earlier, was modified. The spread of defects from the same knotty core can vary according to the sawing system adopted (Fig. 2). In order to standardise procedures and further isolate processing variation, defect core sizes were calculated as the mean of two diameters measured at right angles to each other when the log was centrally aligned, i.e., as for half-taper sawing. In this study, core diameters were measured in each plane, using the SEESAW simulator, after central alignment of the log.

Formulae that combined expressions of clearwood sheath (log size minus defect core size) and clearwood ratio (log size divided by defect core size) were found to provide significantly stronger relationships than formulae which utilised only one of these, now familiar, factors. Many of the formulae tested gave satisfactory results and the final choice became a matter of fine distinction on goodness of fit to both data sets. The index derived was:

$$\text{Pruned Log Index (PLI)} = \left(\frac{\text{D 1.3} - \text{DC}}{10}\right)^{0.5} \times \frac{\text{D 1.3}}{\text{DC}} \times \left(\frac{\text{CVOL}}{\text{LVOL}}\right)^{1.6}$$

where DC = defect core diameter (mm).

The PLI model fitted to Set 1 is given in Table 3 and shown in Fig. 5a. There was sufficient range of pruned log types to allow the model to confirm logic by being asymptotic. The fit of Data Set 2 against the curve derived from Set 1 was very satisfactory (Fig. 5b).

DISCUSSION

The Pruned Log Index presented here is derived from the measurements of actual pruned logs which are routinely obtained whenever logs are analysed by the sawing study methods of Park & Leman (1983), or the cross-sectional analysis system of Somerville (1985). Other systems which may measure two log profiles at right angles to each other, relate these to the central axis of the log, and provide for accurate measurement of defect core would also furnish the variables needed to calculate PLI. The index was derived as a precise expression of pruned sawlog quality and potential and so its application should be limited to actual logs only. Other more general mechanisms, requiring less detailed, predicted, or estimated inputs (e.g., Grade Index, Park 1980; SAWMOD, Whiteside & McGregor 1987), are more appropriate when long-term predictions of expected pruned sawlog quality are required.

Pruned Log Index effectively ranks pruned logs and provides an unbiased basis for direct comparisons. The index may be interpreted, either from results of real sawing studies or from SEESAW simulations, to provide predictions of clearwood

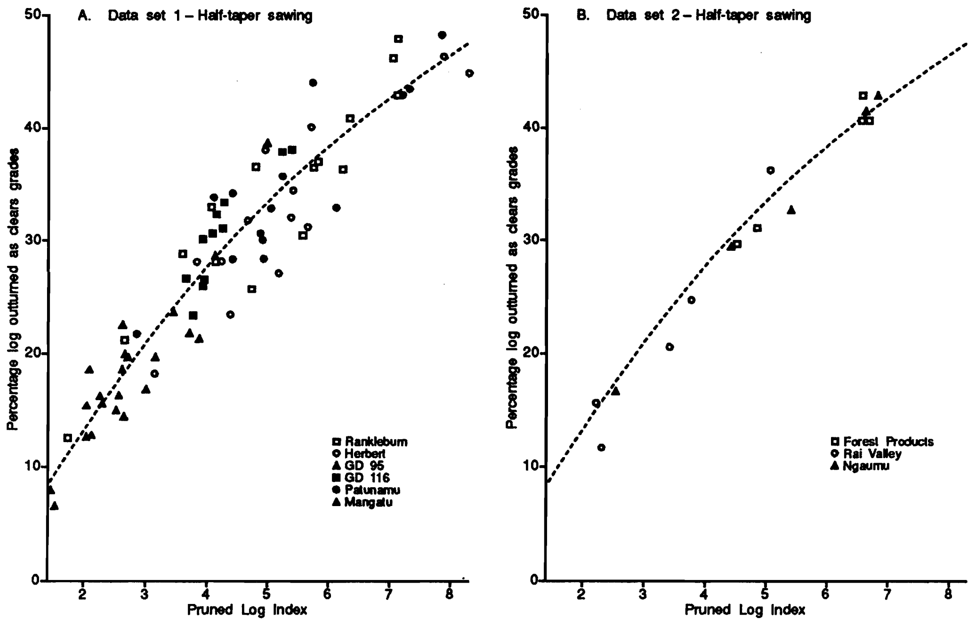

FIG. 5—Relationship between Pruned Log Index (PLI) and conversion to combined clears grades derived from half-taper sawing of Data Set 1 only:
(a) fitted on data points from Set 1;
(b) superimposed over data points from Set 2.

recoveries. Alternatively, the index itself can be used as an immediate appraisal of pruned log quality. Use of the index over two years in timber grade studies, combined with use in SEESAW simulation exercises to define benchmarks (Park 1989b) has shown what the range of PLI values indicate in terms of pruning effectiveness –

PLI values	Pruned log quality
0 – 1.9	pruning has not been effective
2 – 3.9	poor
4 – 5.9	satisfactory
6 – 7.9	good
8 – 9.9	very good
10+	excellent

Pruned Log Index has become a versatile complement to the SEESAW simulator. SEESAW is a well-established tool for investigating the interactions of sawing systems and sawmill variables with pruned logs. However, although the SEESAW "library" consists of over 200 real pruned logs, it is not practical to simulate the sawing of all these for every investigation carried out. The program is interactive and the complete processing of one log takes even an experienced operator approximately 15 minutes.

PLI provides a rationale for selecting the minimum number of samples of the quality required for any given simulation run. With the establishment of PLI it is no longer necessary to prepare every fresh batch of pruned logs to be analysed as input to the simulator. Those without direct access to SEESAW may now utilise all public domain results of past SEESAW simulation exercises by interpreting pruned log quality through PLI. Such interpretations have been found as reliable as having an experienced operator prepare and saw a new sample of logs in the simulator.

The index has already shown its usefulness and versatility when applied to practical forestry. In recent pruned resource evalutions, carried out prior to log sales, on stands from Waratah and Kaingaroa Forests (*see* Somerville *et al.* in prep.; Park 1989b) PLI was used firstly to rank and compare log samples from various sampling points, and then to furnish predictions of conversion to clears grade timber, under a specified saw-pattern, for logs sampled by cross-sectional analysis. PLI also provided a basic statistic on which to determine sample confidence limits.

Because it is independent of sawmill variables, PLI has also proved a useful tool in (i) examining the performance of various sawing systems, via simulation, when sawmill variables are held constant (Park 1989a), and (ii) auditing the performance of various real sawmills on similar pruned log types (Park 1989c). In those situations PLI was taken as an absolute measure of pruned sawlog quality against which to compare sawmill performance in recovering clears grades.

ACKNOWLEDGMENTS

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