IMPORTANCE OF MAINTAINING DEFECT CORES

C. L. TODOROKI

New Zealand Forest Research Institute,
Private Bag 3020, Rotorua, New Zealand

(Received for publication 15 November 2002; revision 13 June 2003)

ABSTRACT

Pruning increases value by encouraging clearwood growth. If pruning is delayed the defect core (DC) expands and clearwood conversion reduces. The objective of this study was to examine defect cores within *Pinus radiata* D. Don stems to determine how well they had been maintained through multiple pruning lifts.

Analysis of 4526 currently standing trees suggests that one-fifth of future crop may have defect cores extending 4 cm or more beyond that initially targeted. Furthermore, results indicate that each 1 cm increase in defect core causes an estimated conversion loss of 2.5%, equivalent to a loss in value of $10/m^3$ sawn (ex-mill). For a direct regime on fertile sites, the cost of the expanded defect core is estimated at $880/ha. Bucking may offer the possibility of recovering some lost value.

The importance and magnitude of defect cores are further emphasised through identification of threshold levels of small-end diameter required to obtain clearwood conversions at a given level. This provides a foundation upon which new log grades can be developed.

Keywords: defect core; diameter over stubs; pruning; clearwood; timber value.

INTRODUCTION

Of the 1.6 million hectares of managed *Pinus radiata* forests in New Zealand approximately 67% is pruned (NZFOA 2003). Pruning encourages the formation of clearwood, which is of significantly higher value than knotty wood, and so increases the value of a stem. Several pruning treatments may be applied. The first pruning lift (low pruning) is generally to 2.2–2.5 m, the second (medium pruning) up to 4 m, and the third (high pruning) up to 6 m. Ultra high pruning, which involves pruning above 6 m, has also been trialled but is not practised on a commercial scale. The height of pruning is determined by the variability in the height of the stand. Where the stand is at a uniform height, trees are pruned to the same height regardless of size. Where there is considerable difference in tree height, pruning height varies from tree to tree.

Regardless of whether fixed or variable pruning is performed, the timing of the pruning treatment is vital. The ideal time specified for pruning is when the diameter over stubs (DOS) of the lowest whorl reaches the target DOS measurement (generally 16–20 cm). When pruning is performed in multiple lifts the pruning should be timed to ensure that the size of the defect core is maintained.

Defect core (DC) is defined as "a hypothetical cylinder containing pith, branch stubs, and occlusion scars. It includes any widening effects due to stem sinuosity at the time of pruning. The term is also used to refer to the diameter of this cylinder" (Maclaren 2000). Defect core includes the DOS of the largest whorl, the depth required to occlude the branches, and the sweep of the log at the time of occlusion. There is a strong relationship between DC and DOS (Park 1982). The relationship (Equation 1), with a correlation coefficient of 0.94, is valid for logs that are nominally straight and between 4.9 and 5.5 m long.

$$DC = 62.976 + 0.995 \times DOS \text{ (mm)} \quad (1)$$

Stand record systems maintain records of DOS measurements. One such system is the Permanent Sample Plot (PSP) database system (Dunlop 1995). The PSP system was developed for monitoring plot growth as well as for experimental research and is supported by forestry companies throughout New Zealand. Another system that records DOS measurements is the Pruned Stand Certification System (Somerville 1995). Diameter over stubs can also be predicted from stand measurements of tree height, height to DOS whorl, diameter at breast height (dbh), and maximum branch diameter (Knowles *et al.* 1987).

The importance of maintaining the defect core through pruning lifts is illustrated by the two logs in Fig. 1. The logs have identical external characteristics and are pruned in two lifts. In contrast to Log A's well-maintained defect core, the delayed second pruning of Log B has resulted in an enlarged defect core. This causes a loss in clearwood conversion from a potential of 74% with the well-maintained defect core to 21% with the enlarged defect core.

While it is apparent from the above example that the inherent value of pruned logs can differ considerably, even with identical external characteristics, both logs attract the same grade by New Zealand domestic log grading criteria (Maclaren 2000). Logs with a small-end diameter (s.e.d.) of 40 cm or more are graded as P1, those with a s.e.d. of 30–39 cm as P2. Restrictions on log sweep also apply.

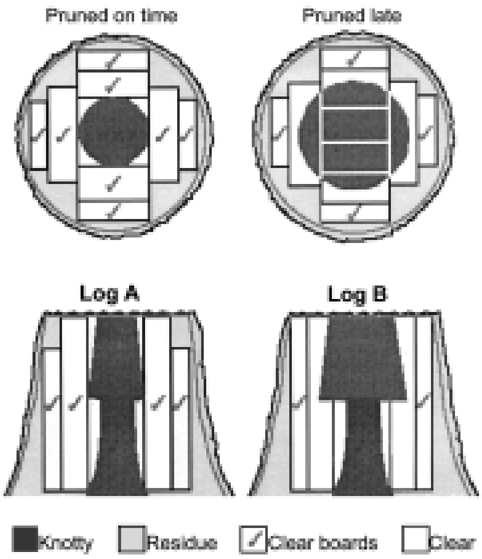

FIG. 1–Two logs of identical size pruned in two lifts

Lack of internal quality recognition is also inherent in log-making tools such as AVIS (Twaddle & Goulding 1989) that grade and cut pruned logs according to size and shape. Rather than being an oversight, this is simply because technology for detecting internal defects is not currently available at the skid site. While research on non-destructive evaluation (NDE) tools such as computed tomographic scanning (Benson-Cooper *et al.* 1982; Funt & Bryant 1987; Schad *et al.* 1996; Schmoldt *et al.* 1999) intensifies and approaches commercial realisation (Wagner *et al.* 1989; Thawornwong *et al.* 2000), benefits of NDE tools and an understanding of the implications of inherent log quality can be gained through use of mathematical models and computer programs.

One such computer program is SAWMOD (Whiteside & McGregor 1987). SAWMOD calculates sawn timber grade percentages using a series of regression models (Cown *et al.* 1987) developed through extensive sawmill studies. Clearwood conversions can be calculated with input of small-end diameter, defect core, log length, sweep, and taper. Timber values can also be calculated with input of a timber pricelist.

The aim of this study was to determine the extent to which defect cores are, or are not, maintained and investigate the implications for clearwood conversion and value through modelling approaches.

MATERIALS AND METHODS

Two independent samples of pruned log and stem data were used. The first sample, comprising 409 logs, was derived from pruned assessments throughout New Zealand of mature stems that had been felled in the 1980s (Park & Leman 1983; Somerville 1985). This sample represented old crop. The second was obtained from measurements of 4526 currently standing trees and represented future crop. This latter sample was procured to demonstrate the relevance of this study to future log supplies and clearwood production in view of the fact that forest management practices have changed substantially over the years. The defect core maintenance of the samples was compared, and clearwood conversions were calculated.

Old crop data included detailed three-dimensional descriptions of external and internal features of pruned logs that were individually mapped, digitised, and stored electronically. The logs were theoretically bucked to 5.4-m lengths (measured from the butt end) to remove the effect of increased log length on small-end diameter, defect core, and sweep. Of the 409 logs in the sample, 98 had been pruned in two lifts and 311 in three lifts. Small-end diameter averaged 41 cm with a standard deviation of 6 cm, defect core 28±4 cm, taper 10±4 mm/m, sweep 7±4 mm/m, and volume 0.83±0.24 m^3.

To measure defect core maintenance within old crop logs, the defect core was determined over two intervals. The first was determined in the usual manner, over the full log length, and represented the defect core that embraced all pruning lifts (DC_Final), while the second recorded defect core at the first pruning lift. This latter defect core, the one that ideally should be maintained throughout pruning lifts, is denoted by DC_Initial. In the absence of DOS height data the defect core due to the first pruning lift was assumed to span from the butt end of the log to 2.6 m from the butt end. The defect core was further tracked through each log at 0.2-m increments from the 2.6-m location to the log small-end. Within-log defect core variation was calculated as the difference between DC_Final and DC_Initial.

Clearwood recovery and timber values were predicted using SAWMOD with the "Improved Clears Recovery", "Visual Grading to Maximise Value", and "Medium Resin Pocket Level" options, and prices as shown in Table 1. Clearwood (No. 1 Clears) was calculated with input of small-end diameter, log length, taper, sweep, and defect core. Clearwood due to multiple-lift pruning was calculated with input of DC_Final. Clearwood conversions that would have resulted had the defect core been maintained throughout the pruning lifts were calculated with input of DC_Initial, with all other variables held constant.

TABLE 1–Timber value ex-mill ($/m^3 sawn)

Grade	Width (mm)	
	<200	200
No.1 Clears	690	720
No.2 Clears	590	630
Cuttings	435	465
Factory	300	300
No. 1 Framing	340	340
No. 2 Framing	215	215
Box	230	230
Boards	215	220
Export Squares		220

Future crop data, comprising DOS measurements of standing trees pruned in two or three lifts, were extracted from the PSP system. The DOS at the first pruning lift and maximum DOS were determined for each stem and, using Equation 1, DC_Initial and DC_Final were calculated. Note that by Equation 1 a 10-mm variation in DOS is equivalent to a 9.95-mm variation in defect core. Within-log defect core variation for future crop was calculated in the same manner as described above.

RESULTS

Examples of defect core against log length are given in Fig. 2 for three logs. Each of the logs shown had been pruned in three lifts and had a small-end diameter of 42 cm. Logs 1, 2, and 3 had taper of 6, 11, and 13 mm/m, and sweep of 11, 6, and 3 mm/m respectively. Log 1 had distinctive defect core zones and a within-log defect core variation of 10 cm derived from a DC_Initial of 21 cm and DC_Final 31 cm. Log 2 had a defect core variation of 5 cm derived from a DC_Initial of 20 cm and DC_Final of 25 cm, while Log 3 had no within-log defect core variation as DC_Initial and DC_Final remained constant at 26 cm.

Clearwood conversions and timber value for each log are given in Fig.3. Log 1, with DC_Final of 31 cm, achieved nearly 23% clearwood conversion from an overall log conversion of 52% and timber value of $405/m^3 sawn (ex-mill). Had the defect core been maintained at 21 cm then an increase in clearwood conversion to 46% and timber value to $500/m^3 could have been achieved. For Log 2, a 14% increase in clearwood conversion and an additional $56/m^3 would have resulted had the defect core been maintained at the initial level. For Log 3, clearwood conversion and timber value remained constant at 36% and $459/m^3. Note that had Log 1 been bucked to give combinations of two shorter logs (ignoring sawcut), then the log sections would have characteristics as given in Table 2.

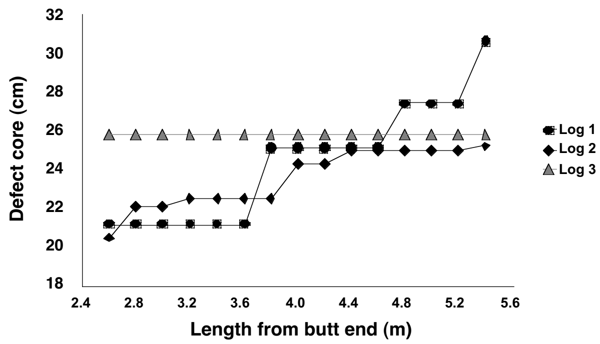

FIG. 2–Within-log variation of defect core

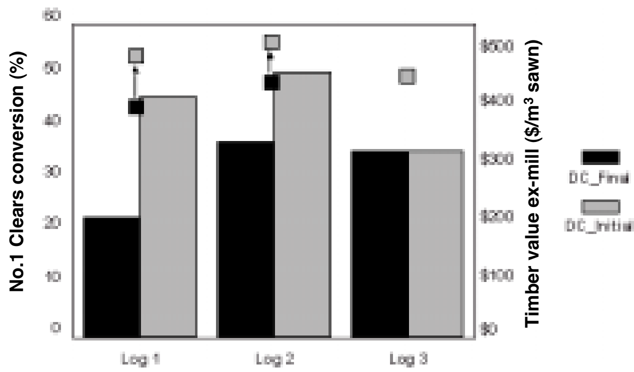

FIG. 3–Actual and initial clearwood conversion (bars) and timber value (upper blocks) for three logs, illustrating the importance of maintaining defect cores

TABLE 2–Characteristics of a full-length log and two shorter logs cut therefrom

	S.e.d. (cm)	Defect core (cm)	Taper (mm/m)	Sweep (mm/m)	Volume (m^3)
Full 5.4 m log	42	31	6	11	0.81
Lower 2.7m log	44	21	4	7	0.43
Upper 2.7m log	42	30	7	7	0.38
Lower 3.6 m log	43	21	8	7	0.56
Upper 1.8 m log	42	30	3	8	0.25

Processing these sections in SAWMOD gave the conversions and values shown in Table 3. Note that the sums of the two shorter log sections ($127 + $86 = $213 and $161 + $57 = $218) exceed the value of the whole ($171).

Loss in clearwood conversion was strongly correlated with defect core enlargement (Fig. 4). A linear regression through the sample had a correlation coefficient of 0.96. As a general rule of thumb, each 1-cm increase in defect core was accompanied by a loss in clearwood conversion of about 2.5%.

TABLE 3–Conversions and timber values for a full-length log and two shorter logs cut thereof

	Clearwood (% sawn)	Log conversion (%)	Timber value ($/m^3 sawn)	Timber value ($/m^3 log)	Absolute value ($)
Full 5.4 m log	23	52	405	211	171
Lower 2.7m log	52	56	527	295	127
Upper 2.7m log	24	55	412	227	86
Lower 3.6 m log	52	55	519	288	161
Upper 1.8 m log	24	55	412	227	57

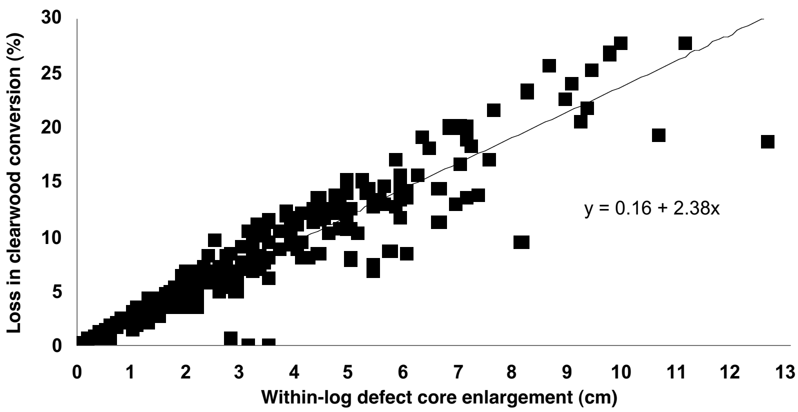

FIG. 4–Conversion losses due to defect core enlargement

Frequency distributions of defect core enlargement for old and future crop are shown in Fig. 5. About 42% of the old crop sample had within-log defect core enlargement of less than 1 cm, 58% (accumulated) of less than 2 cm, 79% less than 4 cm, and the remaining 21% had a defect core enlargement of 4 cm or more. Distributions for future crop were 46% at less than 1 cm, 58% less than 2 cm, 79% less than 4 cm, and 21% of 4 cm or more.

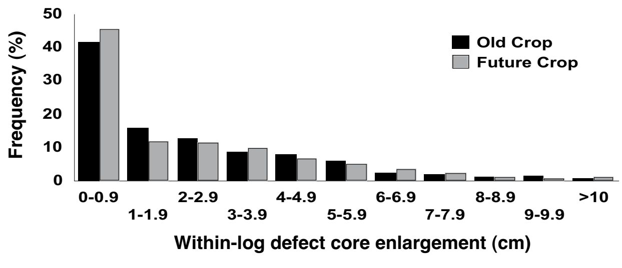

FIG. 5–Defect core enlargement found for old crop and current standing trees

While within-log defect core variation distributions were similar for both samples, the mean defect core of old crop data at the final pruning (i.e., DC_Final) was 28 cm with a 4-cm standard deviation arising from an initial defect core (i.e., DC_Initial) of 26 ± 5 cm. That calculated for future crop was 27 ± 3 cm (DC_Final) arising from an initial mean defect core of 25±3 cm. To test whether the difference between the mean defect core of old and future crop was significant, a 95% confidence interval for the difference was constructed:

$$(\bar{X}_{old} - \bar{X}_{future}) - z \cdot \sigma_{\bar{X}_{old} - \bar{X}_{future}} < \mu_{old} - \mu_{future} < (\bar{X}_{old} - \bar{X}_{future}) + z \cdot \sigma_{\bar{X}_{old} - \bar{X}_{future}}$$

***DC_Final*:** $0.32 < \mu_{old} - \mu_{future} < 1.20$

***DC_Initial*:** $0.26 < \mu_{old} - \mu_{future} < 1.17$

The confidence interval shows that the difference between the mean defect cores of old and future crop is significant since 0 is not in the interval.

With a defect core of 25 cm (equivalent to the sample mean of initial defect core for future crop) and a small-end diameter of 40 cm, clearwood conversions of 33% and timber value of \$446/m^3 (sawn) could be expected, assuming average characteristics of 10 mm/m taper and 7 mm/m sweep. With a 2-cm increase and a 27-cm defect core, conversions and value fall to 27% and \$425/m^3 respectively. At 29 cm, conversions and value fall to 23% and \$404/m^3 respectively, and at 33 cm conversions and value fall to 15% and \$367/m^3 respectively. These results are shown in Fig. 6a and 6b and are extended over a range of log sizes.

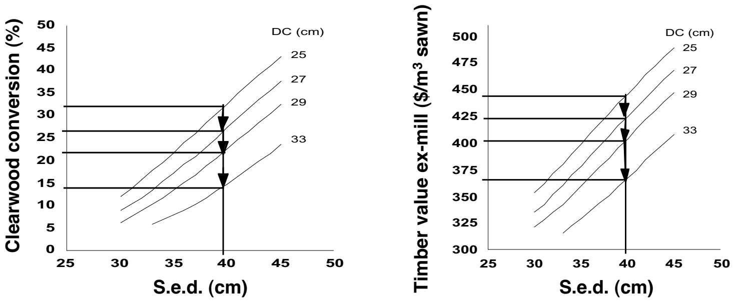

FIG. 6–Clearwood recovery (a) and timber values (b) from 5.4-m logs with 10-mm/m taper and 7-mm/m sweep

The results can also be analysed from the perspective of defining logs from which specific clearwood conversions can be obtained. With a target DOS of 20 cm, equivalent to a 26-cm defect core, a small-end diameter of at least 35 cm is required to obtain 20% clearwood conversion (sawn). A 40-cm small-end diameter is required to obtain 30% clearwood conversion, and a 45-cm small-end diameter to obtain 40%. Further specifications for minimum small-end diameters required to obtain a given level of clearwood conversion are given in Table 4.

DISCUSSION AND CONCLUSIONS

Based on the sample of 4526 standing trees representing the future New Zealand pruned resource, results indicate that for about three-fifths of the resource the defect core is

TABLE 4–Pruned log size small-end diameter (cm) for obtaining clearwood conversions at the stated diameter-over-stubs (DOS) or defect core (DC) (based on 5.4-m logs with 10-mm/m taper and 7-mm/m sweep).

Clearwood (% sawn)	DOS (cm) / DC (cm)					
	16 / 22	18 / 24	20 / 26	22 / 28	24 / 30	26 / 32
20	31	33	35	38	40	42
30	35	38	40	43	45	47
40	39	42	45	47		
50	44	47				

maintained to within 2 cm of that of the initial pruning lift. However, about one-fifth of the resource experienced a 2- to 3.9-cm increase in defect core, and in the remaining one-fifth an increase of at least 4 cm was found. With a target DOS of 19 cm, equivalent to an initial defect core of 25 cm, a 4-cm expansion in defect core to give a final defect core of 29 cm would cause a loss in clearwood conversion of 10% and loss in sawn timber value of $\$42/m^3$ (sawn) for P1 grade logs with a 40-cm s.e.d. At 52% conversion this is equivalent to $\$22/m^3$ (round wood). As a direct regime for fertile pasture sites typically yields 200 m^3 pruned wood/ha (Maclaren 1993), if one-fifth of this is subject to a 10% loss in clearwood conversion then the loss per hectare is estimated at:

$$^1/_5 \times 200\ m^3/ha \times \$22/m^3 = \$\ 880/ha$$

On a national scale with one million pruned hectares the cost is significant.

This is a non-recoverable loss, demonstrating the importance of maintaining the defect core and timely pruning operations.

Bucking within the pruned component of a stem may provide a mechanism for reducing the loss. This was illustrated in the example in which a pruned log with a 10-cm enlargement in defect core was cut in two, giving increased timber value through reduced sweep, higher clearwood conversions, and higher log conversions (Table 2). The example, while simplistic in approach, illustrated the effect of enlarged defect cores on timber value. However, it is not intended that all logs with enlarged defect cores be simply cut in two. The whole stem needs to be taken into account, with bucking made at that position that maximises overall stem value. This leads on to another possibility — that of producing a shorter yet higher-valued butt log, or peeler bolt, and a semi-pruned (or another pruned) second log. The second log with longer lengths of clearwood, and having been cut at a position closer to the butt end, would also have higher wood density than had the second log been cut from higher up the stem. Thus, the quality of the second log would also improve. To determine the benefits of bucking shorter logs an economic analysis of bucking and subsequent manufacturing processes is required.

Development and evaluation of the potential for a semi-pruned log grade is suggested. Then, to estimate the magnitude of potential gains through knowledge of the defect core and from semi-pruned logs, computerised simulations of stem bucking operations can be performed. As intensive data of 3D stem descriptions have been collected in past studies conducted by Forest Research, these can form a basis for future work.

However, the main difficulty with incorporating defect core or DOS information within stem bucking tools lies in the data capture itself. While there have been significant advances in non-destructive evaluation tools, it may be some time before such tools are commercially viable for in-field situations. It is suggested that the high resolution and capability of computed tomographic scanners is more than is required for the type of work described here. Rather than high-resolution images, rapid assessment tools that are capable of assessing the extent (but not detailed content) of the defect core at discrete positions along the pruned length of the stem need to be developed. This is another challenging field for future work.

This study has illustrated the importance of maintaining the defect core throughout pruning lifts. Findings support the recommendation that the inherent value of pruned logs be recognised by the forest industry. To this end it is suggested that current pruned log grade specifications be reviewed and replaced by specifications that consider inherent value. The threshold levels of small-end diameter required to obtain specific levels of clearwood conversion for a range of DOS and defect core sizes (*refer* Table 4) provide a foundation for developing new log grades.

ACKNOWLEDGMENTS

Much gratitude is expressed to Carolyn Andersen for extracting data from the PSP system. Practical comments and suggestions by John Ellis, Mark Dean, Judy Hayes, and the referees are also gratefully acknowledged. This study was funded by the Wood-Fibre Growth and Quality: Tree to Product Programme.

REFERENCES

BENSON-COOPER, D.M.; KNOWLES, R.L.; THOMSON, F.J.; COWN, D.J. 1982: Computed tomographic scanning for the detection of defects within logs. *New Zealand Forest Service, Forest Research Institute, FRI Bulletin No.8*. 9 p.

COWN, D.J.; KIMBERLEY, M.O.; WHITESIDE, I.D. 1987: Conversion and timber grade recoveries from radiata pine logs. Pp. 147–161 *in* Kininmonth, J.A.(Comp.) "Proceedings of the Conversion Planning Conference". *New Zealand Ministry of Forestry, Forest Research Institute, FRI Bulletin No.128*.

DUNLOP, J. 1995: Permanent sample plot system user manual. *New Zealand Forest Research Institute, FRI Bulletin No.187*. 110 p.

FUNT, B.V.; BRYANT, E.C. 1987: Detection of internal log defects by automatic interpretation of computer tomography images. *Forest Products Journal 37(1)*: 56–62.

KNOWLES, R.L.; WEST, G.G.; KOEHLER, A.R. 1987: Predicting 'diameter-over-stubs' in pruned stands of radiata pine. *New Zealand Forest Service, Forest Research Institute, FRI Bulletin No.12*. 25 p.

MACLAREN, J.P. 1993: Radiata pine growers' manual. *New Zealand Forest Research Institute, FRI Bulletin No.184*. 140 p.

———2000: How much wood has your woodlot got? *New Zealand Forest Research Institute, Bulletin No.217*. 135 p.

NZFOA 2003: "New Zealand Forest Industry, Facts and figures 2002/2003". New Zealand Forest Owners Association Inc., Wellington. 25 p.

PARK, J.C. 1982: Occlusion and the defect core in pruned radiata pine. *New Zealand Forest Service, Forest Research Institute, FRI Bulletin No.2*.

PARK, J.C; LEMAN, C.S.E. 1983: A sawing study method for evaluating timber from pruned logs. *New Zealand Forest Service, Forest Research Institute, FRI Bulletin No.47*. 42 p.

SCHAD, K.C.; SCHMOLDT, D.L.; ROSS, R.J. 1996: Nondestructive methods for detecting defects in softwood logs. *US Department of Agriculture, Forest Service, Forest Products Laboratory, Madison, Research Paper FPL-RP-546*.

SCHMOLDT, D.L.; OCCEÑA, L.G.; ABBOTT, A.L.; GUPTA, N.K. 1999: Nondestructive evaluation of hardwood logs: CT scanning, machine vision and data utilization. *Nondestructive Testing and Evaluation 15*: 279–209.

SOMERVILLE, A. 1985: A field procedure for the cross-sectional analysis of a pruned radiata pine log. *New Zealand Forest Service, Forest Research Institute, FRI Bulletin No.101*. 23 p.

———1995: Pruned stand certification — A manual of procedures. (Third edition). *New Zealand Ministry of Forestry, Forest Research Institute, FRI Bulletin No.167*. 28 p.

THAWORNWONG, S.; OCCEÑA, L.G.; SCHMOLDT, D.L. 2000: Investigation of the effect of reducing scan resolution on simulated information-augmented sawing. Pp. 51–62 *in* Kline, D.E.; Abbott, A.L. (Ed.) Proceedings of the 4th International Conference on Image Processing and Scanning of Wood, IPSW 2000, Mountain Lake, Virginia, USA, 21–23 August.

TWADDLE, A.A.; GOULDING, C.J. 1989: Improving profitability by optimising log-making. *New Zealand Forestry 34(1)*: 17–23.

WAGNER, F.G.; TAYLOR, F.W.; LADD, D.S.; McMILLIN, C.W.; RODER, F.L. 1989: Ultrafast CT scanning of an oak log for internal defects. *Forest Products Journal 39(11/12)*: 62–64.

WHITESIDE, I.D.; McGREGOR, M.J. 1987: Radiata pine sawlog evaluation using the sawing log-yield model. Pp. 124–146 *in* Kininmonth, J.A. (Comp.) "Proceedings of the Conversion Planning Conference". *New Zealand Ministry of Forestry, Forest Research Institute, FRI Bulletin No.128*.