INCREASING VALUE FROM PRUNED LOGS WITH PARTIAL KNOWLEDGE OF INTERNAL DEFECTS*

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ABSTRACT

The hypothesis that lumber value increases when the sawpattern embodies partial knowledge of the internal defect structure was tested. Two methods for estimating the internal structure were evaluated: one used annual ring-counts and the other used the definition of defect core. The former method was applied to pruned *Pseudotsuga menziesii* (Mirb.) Franco (Douglas fir) logs from the United States and the latter to logs from New Zealand that, although with similar diameters to the United States logs, were substantially younger, pruned much earlier, and had smaller defect cores. Digital models of the logs were constructed. External shape representations were based on direct log measurements. Internal defects were computer-generated for the United States logs, whereas actual branch stub measurements were used for the New Zealand logs. The models were sawn in the AUTOSAW sawing simulator, and the resultant lumber was graded and priced. The sum of lumber prices established a value for each log. That value was compared with lower and upper bounds derived from parallel simulations based on volume-optimising and value-optimising sawpatterns, respectively. The lower bound assumed no *a priori* knowledge of internal defects while the upper assumed full *a priori* knowledge.

With the annual ring count method there was no significant difference in mean log value when compared to the lower bound; however, potential to increase value, demonstrated by the difference between lower and upper bounds was significant at 3%. With the defect core method a significant increase of 5% was found and potential to increase value was nearly 11%.

Keywords: pruned logs; nondestructive evaluation; clearwood; value.

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INTRODUCTION

The internal defect structure of pruned logs is important as knot-free wood created through pruning is of higher value than the knotty wood that it grows over and conceals. To extract as much of the high-valued knot-free wood as possible through sawing requires *a priori* knowledge of the knot-free zones within logs, which in turn requires *a priori* knowledge of internal defects. However, knowledge of internal defects is not incorporated in systems that allocate sawpatterns based on product mix, opening face decisions, and log shape.

To obtain *a priori* knowledge of internal defects requires non-destructive internal scanning technology such as computed tomography, sound wave transmission, or impulse radar. Computed tomography was used to examine images of internal defects within pruned *Pinus radiata* D. Don (radiata pine), Douglas fir, *Acacia melanoxylon* R.Br. (Australian blackwood), *Eucalyptus delegatensis* R.T.Baker, and *Nothofagus fusca* (Hook.f.) Oerst. (red beech) logs (Benson-Cooper *et al.* 1982) and within *Quercus* spp. (water oak) logs (Wagner *et al.* 1989). Image examination by visual inspection was replaced with automated defect interpretation on scanned images of *Thuja plicata* Donn ex D.Don (cedar), *Tsuga heterophylla* (Raf.) Sarg. (hemlock), and Douglas fir (Funt & Bryant 1987). Extension to 3-D log rendering and simulated sawing was proposed by Schmoldt *et al.* (1999) for hardwood logs. Because of the vast quantities of data associated with each image, data condensation techniques were used to reduce the data to log and defect profiles. Reductions in data can also be achieved at an earlier stage through reducing scanning resolution which enables, in principle, greater scanning speeds with little loss in lumber value (Thawornwong *et al.* 2000). In addition to the large data requirements, another disadvantage of computed tomography is the very high cost. Substantially cheaper non-destructive technologies such as sound wave transmission and impulse radar can also detect internal degradation (Schad *et al.* 1996). These lesser resolution tools are of interest because they represent a trade-off between technological costs and potential to add value.

Potential for adding value has been investigated through simulation studies. Imprecise knowledge of internal defects added an average of 13% in value over that obtained with no *a priori* knowledge of internal defects in simulations with a fixed-size cant sawpattern applied to 80 *Pinus radiata* log models (Todoroki 2003). A different study in which defect knowledge was considered only when defects were exposed on the sawn surfaces at the secondary breakdown stage with the edger, showed an average increase in value of 3% (Todoroki 2001). When full internal defect knowledge was considered prior to sawing there was an average increase in value of 18% in comparison to a volume-optimised solution with no *a priori* knowledge of internal defects. Although limited in terms of sample size (12 logs) and sawpattern (through-and-through sawing was used, thus all flitches were processed at the edger) trade-offs between no *a prior* knowledge of internal defects, partial knowledge, and full knowledge were highlighted.

We hypothesised that increased value can be extracted from a pruned log when partial knowledge of the internal defect structure is embodied within the sawpattern. Two representations of the internal defect structure were tested — one was based on annual ring counts, the other used the following definition of defect core: "The diameter of a hypothetical cylinder containing pith, branch stubs, and occlusion scars and including widening effects due to stem sinuosity at the time of pruning" (Maclaren 2000). Value was derived through sawing simulations with AUTOSAW (Todoroki 1990, 1997). Two further sets of simulations were performed to establish lower and upper bounds on value with the lower bound assuming no *a priori* knowledge of internal defects and the upper full *a priori* knowledge. Value comparisons were made between the partial-knowledge values and those of the lower and upper bounds.

DATA

The pruned Douglas fir logs that formed the basis for this study were grown in two geographically disparate locations. One sample, comprising 97 logs, was sourced from the US Pacific Northwest (Washington State, west side of the Cascade Mountains) from a site for which the 100-year site index averaged 44 m (or 145 feet) (Reukema 1972). Trees, selected on diameter at breast height at time of pruning and on subsequent growth, were from all crown classes and had been pruned when the stand was aged 38 years. Because of this, there were few or no live branches removed during pruning. At time of harvest the stand was 75 years old. The harvested logs were measured lengthwise, large- and small-end diameters were measured in two axes, and the extent of internal defects was estimated in two axes at the large and small ends, through annual ring counts to year of pruning. An allowance was added for occlusion using the Petruncio ROO equation (Petruncio *et al.* 1997). After measuring, the pruned logs were processed through a sawmill primarily into structural lumber.

The other sample, comprising 61 logs, was sourced from plantations in the North and South Islands of New Zealand (Golden Downs, Longwood, Mamaku, Reefton, Waimihia, and Waiotapu). They ranged in age from 27 to 51 years, with a mean age of 42 years, and had been pruned in multiple lifts with the first pruning applied when the stands were aged about 10 years and the second at about 15 years (C.L.Todoroki & I.P.McInnes unpubl. data). The logs were measured lengthwise and crosswise in two axes and deviations of the geometric centre from a central string line were recorded. The logs were cross-cut at intervals of 20 cm into discs. The location of the pith on each cross-section was recorded and then the clearwood was cut away with an axe to expose the occluded branch stubs which were measured and their locations recorded.

On average the United States and New Zealand logs were of similar size, each with mean small-end diameter of 39 cm, but defect cores of the United States logs were substantially larger averaging 36 cm in comparison to the 27 cm of the New Zealand logs. Statistics of the log samples are provided in Table 1.

TABLE 1–Sample statistics of the pruned Douglas fir logs.

	Length (m)	SED (cm)	LED (cm)	Sweep (mm/m)	Volume (m^3)	DC (cm)
US sample of 97 logs						
Mean	5.1	39	51	0*	0.9	36
Std deviation	0.1	9	12	0*	0.4	8
Minimum	5.0	20	24	0*	0.2	18
Maximum	5.5	57	73	0*	1.7	53
NZ sample of 61 logs						
Mean	5.3	39	51	7	0.8	27
Std deviation	0.9	8	10	3	0.3	5
Minimum	3.6	24	31	2	0.2	17
Maximum	7.2	65	84	19	2.0	41

SED = small-end diameter
LED = large-end diameter
DC = defect core
*Sweep data not measured. Zero sweep assumed in digital log models.

Measurements for external geometry and internal defects were used to construct each log into a digital model. Because the logs had been measured in two axes, cross-sectional representations for all log models were elliptical. Models of United States logs were straight (as sweep had not been measured), uniformly tapered, and, as the extent of internal defects had been estimated only at the log ends, the internal defect structures comprising branch stub representations and pith were computer-generated. For the United States logs, branch stub representations were proportionately scaled between the large- and small-end ring-count estimates, generated at regular intervals that precluded the production of clearwood within the defect core, and radiated from a straight and centrally located pith. In contrast, models of New Zealand logs were swept, irregularly shaped, and had irregularly spaced branch stubs that radiated non-uniformly about a wandering pith.

By definition and due to the assumption of straightness, defect core of the United States log models was equivalent to the large-end estimate based on ring counts, with occlusion allowance. In trees where little growth occurred after pruning, defect core exceeded small-end diameter. This occurred in 28 of the United States logs and one New Zealand log and caused clearwood sheath (small-end diameter minus defect core) to be negative.

SAWPATTERNS

Cant sawing was simulated using AUTOSAW, and cant size and positioning were allocated according to the degree of *a priori* internal defect knowledge (Partial, Nil, or Full). With Partial, cant size was allocated according to the defect core measures and the cant was positioned to optimise total lumber volume. With Nil, the cant was positioned to optimise volume and cant size was allocated according to small-end diameter. With Full, both cant size and position were allocated such that optimal lumber value was attained.

Five cant widths could be sawn: 100, 150, 197, 251, and 302 mm. For Partial, the cant was 100 mm when the defect core was less than 185 mm; thereafter, for each successive 50-mm increment in defect core, cant size was increased to the next size available (150, 197, 251, or 302 mm). For Nil, cant widths were allocated according to small-end diameter (SED) as follows:

cant 302 mm when SED > 425 mm,

cant 251 mm when 375 < SED ≤ 425 mm,

cant 197 mm when 325 < SED ≤ 375 mm,

cant 150 mm when 275 < SED ≤ 325 mm,

cant 100 mm when SED ≤ 275 mm.

For Full, any one of the five cant sizes could be allocated, dependent upon the optimal value scenario.

A schematic representation of the Nil, Partial, and Full sawpatterns super-imposed over a log with the corresponding degree of internal defect knowledge is shown in Fig. 1.

Lumber was graded into four categories: (a) knot-free, (b) knots on one surface only, (c) knotty both surfaces, and (d) knotty both surfaces with pith. Lumber value was calculated using scaled prices to overcome price fluctuations. For example, D Select category (equivalent to knot-free grade) ranged from US$583 to US$900

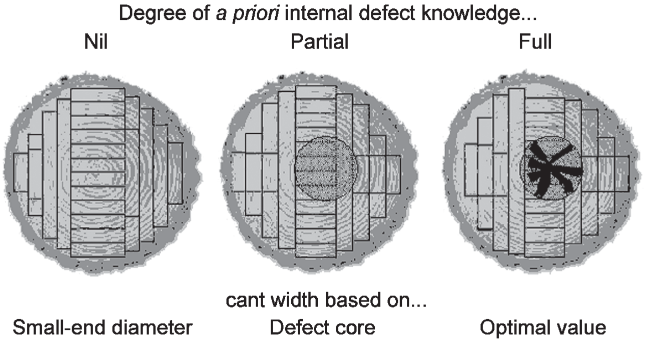

FIG. 1–Schematic representation of the three sawpatterns.

(dollars per thousand board feet), and Economy (which may contain pith and be knotty on both surfaces) from US\$108 to US\$195 during the 10-year period from 1993 to 2002 (Haynes & Fight 2004). By dividing by the price of knot-free grade (average of 10-year period 1993–2002), a weight of 1.0 was assigned to knot-free grade, 0.85 to knotty on one surface only, 0.30 to knotty both surfaces, and 0.25 to knotty both surfaces with pith.

STATISTICAL ANALYSIS

Value comparisons were tested for statistical significance using Students t-Test with a 95% confidence interval. Values derived from Partial were compared with those of Nil and Full. Values from Full were also compared to those of Nil. Where the sawpatterns for Partial, Nil, and Full were identical because the same cant width and position had been allocated, sub-samples that did not contain duplicates were formed and paired T-tests were repeated on the sub-samples.

RESULTS

Differences in value were significant ($p < 0.0001$) for all but the Partial and Nil comparisons of the United States sample and sub-sample using ring counts to estimate the internal structure (Table 2). Results from each of the comparisons follow.

Partial and Nil *a priori* Internal Defect Knowledge Value Comparison

Cant width and position for Partial and Nil were identical for 42 of the 97 United States logs and 24 of the 61 New Zealand logs (Table 2).

Ring count estimate of internal structure

No significant difference ($p = 0.40$) in value between Partial and Nil was found for either the United States 97-log sample (mean values of 0.227 for both Partial and Nil) or the United States 55-log sub-sample (mean values of 0.138 and 0.137 respectively).

Defect core estimate of internal structure

Significant differences ($p < 0.0001$) were found for both the New Zealand sample and New Zealand sub-sample value comparisons. Mean value with Partial for the 61-log sample was about 5% greater than that obtained with Nil (values of 0.273 and 0.260 for Partial and Nil respectively), and about 7% greater for the 37-log sub-sample (values of 0.312 and 0.291 respectively).

Value difference tended to increase with increasing clearwood sheath (Fig 2).

TABLE 2–Paired t-Test comparison of lumber value from three sawing strategies with United States and New Zealand pruned logs.

Sample	Comparison	$\bar{x}_1$	$\bar{x}_2$	$\bar{x}_1–\bar{x}_2$	95% CI* for $\mu_1–\mu_2$	*t-Value*	*Pr* > |*t*|
US, 97	Partial, Nil	0.227	0.227	0.000	[–0.001, 0.002]	0.84	0.4006
US, 55		0.138	0.137	0.001	[–0.001, 0.004]	0.84	0.4027
NZ, 61		0.273	0.260	0.013	[0.007, 0.018]	4.63	<0.0001
NZ, 37		0.312	0.291	0.021	[0.013, 0.029]	5.25	<0.0001
US, 97	Full, Partial	0.234	0.227	0.007	[0.005, 0.008]	8.77	<0.0001
US, 79		0.230	0.222	0.008	[0.007, 0.010]	9.69	<0.0001
NZ, 61		0.288	0.273	0.015	[0.011, 0.020]	7.48	<0.0001
NZ, 54		0.276	0.259	0.017	[0.013, 0.022]	7.97	<0.0001
US, 97	Full, Nil	0.234	0.227	0.008	[0.006, 0.009]	9.53	<0.0001
US, 83		0.223	0.215	0.009	[0.007, 0.010]	10.38	<0.0001
NZ, 61		0.288	0.260	0.028	[0.022, 0.034]	8.89	<0.0001
NZ, 59		0.293	0.264	0.029	[0.023, 0.035]	9.09	<0.0001

* CI = confidence interval

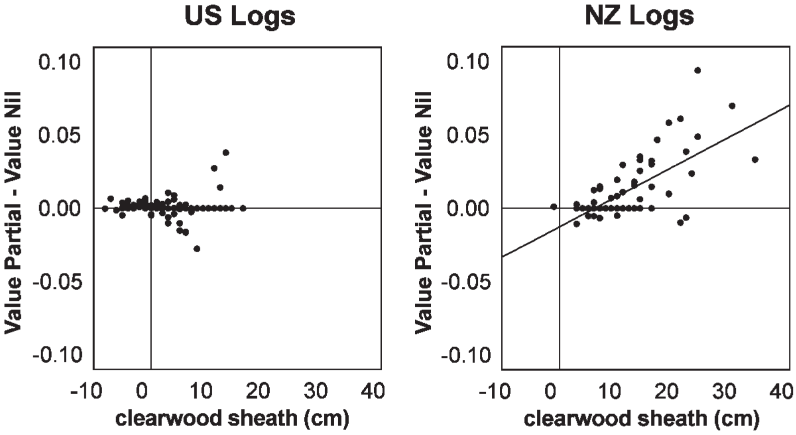

FIG. 2–Value difference between sawpatterns based on partial and no *a priori* knowledge of internal defects using ring counts for estimating the internal structure of the United States sample and defect core for New Zealand sample.

Partial and Full *a priori* Knowledge Value Comparison

Significant differences ($p < 0.0001$) between Partial and Full were found for both United States and New Zealand samples and both sub-samples (Table 2).

Ring count estimate of internal structure

Mean value for the 97-log United States Full sample was about 3% greater than that obtained for Partial (0.234 and 0.227 respectively), and with the 83-log sub-sample about 4% greater (0.230, 0.222).

Defect core estimate of internal structure

Within the New Zealand 61-log sample the increase in value was nearly 6% (0.288 and 0.273 respectively), and nearly 7% for the 54-log sub-sample (0.276, 0.259).

Full and Nil *a priori* Internal Defect Knowledge Value Comparison

Value differences between Full and Nil were significantly different ($p < 0.0001$) for both United States and New Zealand samples and for both sub-samples (Table 2).

Ring count estimate of internal structure

Mean value for Full with the 97-log United States sample was about 3% greater than that obtained for Nil (0.234 and 0.227 respectively), and about 4% greater for the 83-log sub-sample (0.223 and 0.215 respectively). The value difference tended to increase with increasing clearwood sheath (Fig 3).

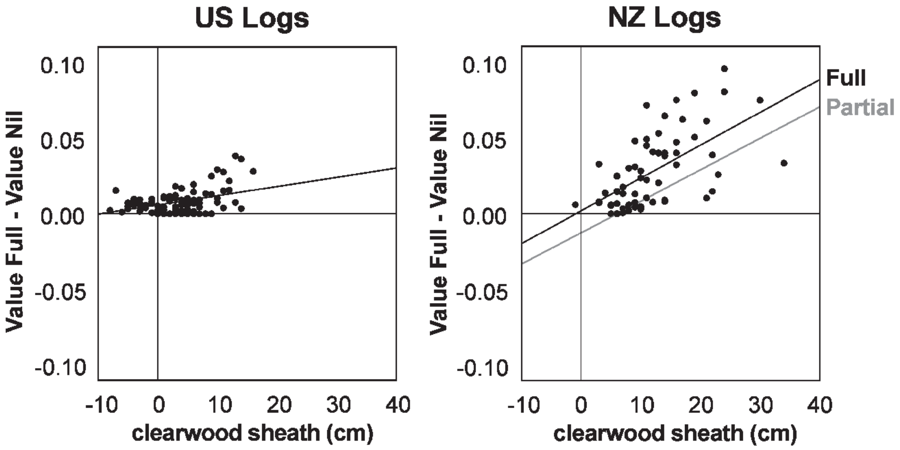

FIG. 3–Value difference between sawpatterns based on full and no *a priori* knowledge of internal defects using ring counts for estimating the internal structure of the United States sample and defect core for the New Zealand sample.

Defect core estimate of internal structure

Within the New Zealand sample all but two pairs of sawpatterns were unique. The statistically significant increase in value was nearly 11% for the New Zealand 61-log sample (0.288 and 0.260 respectively) and 59-log sub-sample (0.293, 0.264). Again a trend of increasing value difference with increasing clearwood sheath was observed (Fig 3). The gap between Full and Partial shown in Fig. 3 represents value-adding potential.

CONCLUSIONS

Based on these findings, we do not reject the hypothesis that increased value can be extracted from pruned logs when the sawpattern incorporates some knowledge of the internal defect structure. The ring-based method we tested was applied to log models with uniformly distributed internal defects of constant taper enclosed within relatively small clearwood sheaths. These combined features reduced the potential for added value. On average only 3% added value was gained through full knowledge of internal defects and so, with partial knowledge of internal defects, there was no significant increase over the no-knowledge alternative. This contrasts with the 11% value-adding potential with full knowledge and 5% increase with partial knowledge of the larger clearwood-content New Zealand logs modelled from measurements of individual branch stubs.

We surmise that we have found a lower bound or tolerance on our data resolution in the structure of the internal knotty core. Further simulations using log models with detailed internal structures (as for the New Zealand log models) and a ring-based estimate for representing the internal defect structure (as for the sawpatterns for United States logs) will be useful in resolving this.

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