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RECOVERY FROM SIMULATED SAWN LOGS WITH SWEEP

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ABSTRACT

A sawing simulator, AUTOSAW, was used to examine the effect of increasing sweep on lumber recovery. Sample material consisted of 51 logs from 22 western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) trees in western Oregon, United States. All knots on the 4.9-m logs were measured, mapped, and converted into 3-dimensional digital formats. The digital logs were then increasingly bent, in 25.4-mm (1-inch) increments, with the bend occurring at the mid-point for one set of logs and at quarter-way from the log small-end for another, and sawn into primarily structural grade dimension lumber. On average, conversion decreased at a rate of 10% for each 100-mm increase in sweep, equivalent to a decrease of 5–7% for each 0.1 unit increase in sweep-to-diameter (s/d) ratio. Conversion losses were represented by an exponential decay function. There was no significant difference in conversions between the two sets of logs; however, the rate of loss of Select Structural and 1 Common lumber was greater for logs bent at the mid-point when sweep was within 51 to 152 mm (2 to 6 inches). Whereas the rate of loss of lower grades was represented by linear functions, those for higher grades and lumber value per cubic metre of log volume were described by exponential decay functions. A 5% loss in value was recorded when s/d equaled 0.09 for logs with diameter less than 200 mm, and for larger logs the ratio was 0.07.

Keywords: AUTOSAW; sweep; conversion; grade recovery; value; modelling; *Tsuga heterophylla*.

INTRODUCTION

Log straightness has long been recognised as an important quality characteristic and has featured prominently in both log grading rules and tree breeding programmes (Cown *et al.* 1984), because a proportion of crop trees inevitably contain some form of stem curvature or deformation and, as succinctly stated by Todoroki & Rönnqvist (1998), not all logs are straight. Swept logs give rise to product recovery losses when straight sawn (Dobie 1964; Brown & Miller 1975; Dobie & Middleton 1980; Cown *et al.* 1984; Todoroki 1995; Taylor

& Wagner 1996). Simple rules-of-thumb have been derived for the yield reduction per each 0.1 increase in the ratio of log sweep (measured as the maximum deviation from straightness) to small-end diameter: 7% by Dobie & Middleton (1980), and 5% by Cown *et al.* (1984). The 7% rule of thumb was developed based on kiln-dried and dressed lumber sawn from lodgepole pine (*Pinus contorta* Loudon) logs approximately 15 cm in diameter, and the 5% rule was developed from green lumber sawn from *P. radiata* D. Don butt logs with mean small-end diameter of approximately 40 cm. Recent work has focused on curve-sawing of the log (sawing parallel to the curvature) as a means of reducing—or eliminating—yield losses due to sweep (Wang *et al.* 1992; Todoroki & Rönnqvist 1998; Wagner *et al.* 2002).

In addition to yield losses, sweep and other forms of stem deformation are thought to have a negative impact on wood quality. However, in a study of sinuous ("wavy") Douglas fir (*Pseudotsuga menziesii* (Mirb.) Franco) stems, Spicer *et al.* (2000) concluded that, except in severe cases, sinuosity had a minor impact on wood quality. Tree lean and stems with pronounced curvature, on the other hand, have been associated with compression wood and grain deviation, but even straight vertical stems have been found to contain compression wood (Low 1964; Shelbourne 1966). The relationship between external stem geometry and the distribution of compression wood remains a topic of keen interest, with studies on clonal pairs of straight and swept stems continuing in New Zealand today.

Because every log is unique and can be sawn into boards only once, experimentation with real logs in product recovery studies contains considerable variation that can mask underlying relations. One way to eliminate part of this variation is to use sawing simulation with digitised images of the same real logs, which can be replicated as many times as necessary in an experimental design. Another advantage of simulation is that the extremes can be examined when looking for relationships. Our aim is to explore and quantify the range of variation in sweep, from no sweep to excessive sweep, and to use sawing simulation as a tool to isolate and understand the potential variation in lumber recovery.

The focus in this study was on quantifying losses due to straight sawing, using the AUTOSAW sawing simulator (Todoroki 1990) with the objective being to analyse lumber recovery as a function of varying degrees of sweep. Data were obtained from a set of actual straight logs that were measured and digitised, then increasingly bent and resawn with the AUTOSAW sawing simulator. Results are presented in terms of the degree of sweep, and the ratio of sweep to small-end diameter.

METHODS

Log Sample

Data were collected from 26 western hemlock trees from former Willamette Industries land in Clatsop and Tillamook counties of western Oregon, United States. The areas where the trees were felled were selected to represent the range of growth conditions for western hemlock (*see* Barbour *et al.* 2004). Knot characteristics were mapped from the butt of the tree to the height where the log diameter had decreased to approximately 80 to 90 mm. Because of errors in field data collection, only 22 of the 26 trees were available for use in this study. For each tree logs were created in length units of approximately 5 m. The length of the last log from a tree was dependent on the top diameter, the minimum small-end diameter accepted being 127 mm. One more criterion limited log length to between 2.5 and 5 m, in 0.6-m increments. This process of segmenting the data resulted in 51 usable logs.

For each tree, all externally visible knots were measured for their size, radial and longitudinal position, and the associated log diameters. In addition, knots were assessed as being either live or dead. Knots were considered live if the wood was continuously ingrown at the log surface, and dead if separation existed between knot and stem. This distinction follows the lumber grading rules (WWPA 1998) distinguishing between sound tight knots and loose knots. The tree stems were bucked into logs and a subset of 51 of those logs that were essentially straight and approximately 5.0 m long was selected for this study. Characteristics of the log sample, grouped according to small-end diameter (s.e.d.), are shown in Table 1.

TABLE 1–Characteristics of the 51 straight logs

Log sort	Sample size	s.e.d. (mm)	Length (m)	Taper (mm/m)	Number of branches	Mean branch diameter (mm)
1	7	140±11	4.99±.05	11±6	86±31	12.0±3.8
2	11	178±13	5.02±.04	14±7	98±31	14.2±7.0
3	7	232±18	5.00±.07	13±4	77±24	15.6±6.4
4	11	288±13	5.00±.07	13±4	65±18	18.2±8.2
5	15	402±58	5.02±.07	16±10	58±15	19.6±8.0

Sawing Simulation

From these field data, 51 individual log data files were created as input to AUTOSAW for sawing simulation. When the log diameter, knot description, and location information is read by AUTOSAW, a 3-dimensional depiction of the log is created (Todoroki 1990) with live knots depicted as cones and dead knots as cylinders (Todoroki 1997). Note that because tracing knots inside the logs with tomographic equipment (Taylor et al. 1984) was not available to this study, knots assessed as dead were assumed to remain dead (cylindrical) for the first 20% of the distance from the surface of the log then live (conical) for the remaining 80% of the distance to the pith.

The 51 digitised logs were systematically bent in increasing 25.4-mm (1-inch) deflections, from 25.4 to 406.4 mm (1 to 16 inches) representing minimal to extreme sweep conditions. The bend was parabolic, and was applied at the log midpoint for one set of 16 deflections and at one-quarter the distance from the log small-end (at 1.22 m, 4 feet) for a second set. The former set simulated logs with uniform sweep while the latter simulated logs with non-uniform sweep. Thus, one set of 51 straight logs and 32 sets of 51 swept logs were created for this study, for a total of 1683 replicate logs.

In this study the goal was to simulate a sawmill producing mainly structural grade dimension lumber (for the United States market) 2 inches thick and 4 to 12 inches wide and the occasional 1-inch boards from the outside of the log. Thus, sawing instructions to the AUTOSAW program were to saw the 1683 logs into construction grades of dimension lumber after removing occasional 4/4 jacket boards from the outside of the log. Logs with sweep were placed "horns up" and "sawn" with a 3.7-mm sawkerf into flitches and a cant.

Cant size varied with log size and was 100 mm for logs with s.e.d. less than 156 mm, 150 mm for logs ranging in s.e.d. from 156 to 204 mm, 197 mm for 205–260 mm s.e.d., 251 mm for 261–313 mm s.e.d., and 302 mm for larger logs. Cants were sawn using a 3.7-mm sawkerf, while flitches were sawn using a 4.8-mm sawkerf. Sawing instructions, allowances, and other variables are described in Table 2.

TABLE 2–Parameters used in the sawing simulations

LOG POSITIONING	Small end presented to saw, and rotated to "horns up" position with log oriented for half taper sawing				
SAWKERFS	Log and cant breakdown: 3.7 mm Flitch breakdown: 4.8 mm				
CANT DIMENSIONS (mm)					
Nominal	99	149	196	250	301
Actual	100	150	197	251	302
Log sort	1	2	3	4	5
BOARD DIMENSIONS (mm)					
Nominal thicknesses	23.5	43.2			
Actual thicknesses	24.0	44.0			
Nominal widths	99	149	196	250	301
Actual widths	100	150	197	251	302
Minimum length	1829				
Dock step	305				
Wane limit	12				
GRADING RULES:					
Common (1" × 4 – 12")			WWPA Rule Sections 30.11 – 30.15		
Structural Light Framing (2" × 4")			WWPA Rule Sections 42.10 – 42.14		
Structural Joists and Planks (2" × 6 – 12")			WWPA Rule Sections 62.10 – 62.14		

As the occasional board sawn from the severely swept logs demonstrated severe wane on both wide faces, AUTOSAW evaluated both upper and lower faces simultaneously to ensure accurate edging and trimming. In effect, this assumes that scanning capability is not only available for both upper and lower board faces but is also coupled to ensure that wane criteria are met on both faces.

In addition to calculation of lumber tallies by volume and grade, conversion factors and lumber value were examined. Using the year-to-date prices (Table 3) in WWPA (2003) a weighted price was determined for each of four grade categories. The first category consisted of high-quality lumber, graded as Select Structural or 1 Common, and was priced at $380.75/MBF. The second category consisted of No. 2 & Btr and 2 and 3 Common and was priced at $343.56/MBF. The third consisted of No. 3 and 4 Common and was priced at $182.84/MBF, while the fourth and final category, consisting of the lowest grades Economy and 5 Common, was priced at $135.16/MBF.

Results were compared primarily in terms of the degree of sweep deflection in preference to comparisons with the ratio of sweep deflection to small-end diameter. While the latter has been more commonly cited in other studies, the former is more appropriate to this study as comparisons of factors with sweep are based on the same logs that are identical in terms of diameter distributions and knot structures and differ only in the degree

TABLE 3–Hemlock and true firs, dry/surfaced. Year to date volume and prices (WWPA 2003) used to estimate value.

Category	Items	Volume MBF	$/MBF	Weighted price
Select Structural	2×4	3 219	$407.13	$380.75
& 1 Common	2×6 & wider	14 728	$374.99	
No. 2 & Btr	2×4	39 480	$363.51	$343.56
& 2 & 3 Common	2×6	74 033	$342.19	
	2×8	34 745	$342.04	
	2×10	59 109	$336.57	
	2×12 & wider	27 142	$335.43	
No. 3	2×6	6 696	$181.92	$182.84
& 4 Common	2×8	907	$173.29	
	2×10	2 445	$184.85	
	2×12 & wider	1 422	$189.82	
Economy	2×6	5 182	$140.86	$135.16
& 5 Common	2×8	640	$115.46	
	2×10	1 135	$124.32	
	2×12 & wider	518	$126.20	

of sweep. This is in contrast to comparisons with the sweep to diameter ratio that have differing sample sizes, diameter distributions, and knot structures. Some of these differences are illustrated in Fig. 1: the top left bar graph shows the distribution of small-end diameter at s/d = 0. This distribution is applicable to all 51-log sets described earlier. However, when s/d is not equal to zero, the number of logs grouped by s/d ratio (in classes of size 0.2) alters: it increases from 51 logs at a ratio of 0.0 to 112 logs at 0.2, fluctuates between 105 and 108 in the next three ratio classes, then decreases steadily from 85 logs at a ratio of 1.0 to two logs at a ratio of 3.2. This progression is shown in the bar graphs as well as the tendency for small-end diameter to decrease with increasing s/d ratio.

The REG (linear regression) and NLIN (nonlinear regression) procedures in SAS (SAS Institute Inc. 1999) were used to fit models to the lumber yield data and estimate the parameters. The Marquardt (1963) iterative method was chosen for the nonlinear models with starting values of the parameters to be estimated obtained from regression fitting of plots in Excel. In comparisons between the uniformly-swept and non-uniformly-swept samples, statistics for computing confidence intervals were calculated and Student's t-Test analysis was performed using the hypothesis that the sample means were equal to zero and a 95% confidence interval. The Pearson product moment correlation coefficient, a dimensionless index that ranges from –1.0 to 1.0 inclusive, and reflects the extent of the linear relationship between two paired data sets, was also computed.

RESULTS

Conversion

Log conversion decreased linearly, at a rate of about 10% for each 100-mm increase in sweep deflection (Fig. 2). The variation about this linear trend could be attributed primarily

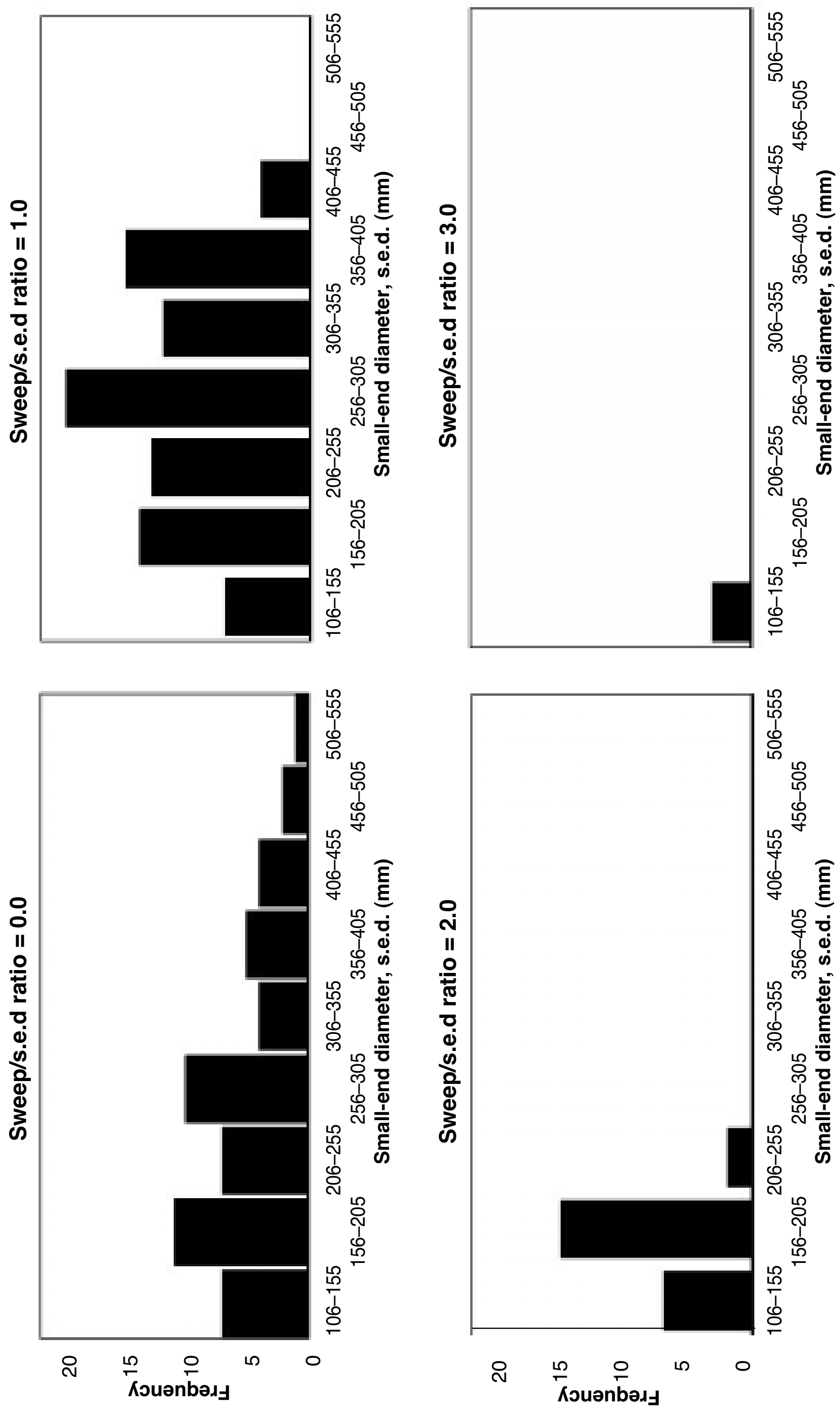

FIG. 1–Diameter distributions for four groupings of logs by s/d.

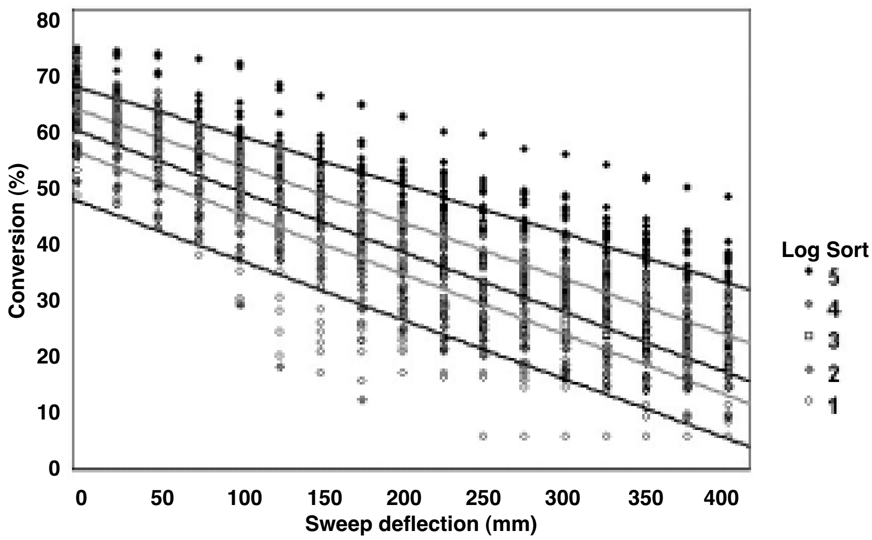

FIG. 2–Relationship between conversion and sweep deflection for the 1683 logs.

to log size, as measured by small-end diameter. For the straight logs of Log Sort 1 (mean s.e.d. 140 mm), conversion averaged 46.7% and decreased at a rate of 10.2% for each 100-mm increase in sweep deflection. For those in Log Sorts 2 and 3, conversion averaged 55.2% and 58.9% respectively and declined at a rate of 10.4% for each 100-mm increase in sweep deflection. Mean conversions for straight logs in Log Sorts 4 and 5 were 62.6% and 66.5% respectively and the rates of decrease were 9.7% and 8.4% respectively. The corresponding linear regressions and statistics are given in Table 4.

Closer examination of four of the sweep deflection classes (0, 102, 203, and 406 mm or 0, 4, 8, and 16 inches) revealed a nonlinear and approximately logarithmic relationship between small-end diameter and conversion for a given sweep (Fig. 3). There was little difference in conversions between the logs bent at the quarter and mid-points, but with a sweep deflection of 203 mm (8 inches) conversion trends diverged for logs larger than 200 mm, with the lower conversions for logs bent at the mid-point. For straight logs (0 sweep) conversions averaged between 50 and 70%. When logs were bent by 102 mm (4 inches) conversions reduced to about 30–60%, and for those bent by 203 and 406 mm

TABLE 4–Linear regression statistics for predicting conversion percentage (y) given sweep (x in millimetres).

Log sort	Linear regression	R^2	n	Standard error intercept	Standard error x
1	y = 46.7 – 0.102x	0.83	231	0.7	0.003
2	y = 55.2 – 0.104x	0.82	363	0.6	0.003
3	y = 58.9 – 0.104x	0.89	231	0.6	0.002
4	y = 62.6 – 0.097x	0.89	363	0.4	0.002
5	y = 66.5 – 0.084x	0.79	495	0.5	0.002
All	y = 59.5 – 0.096x	0.60	1683	0.5	0.002

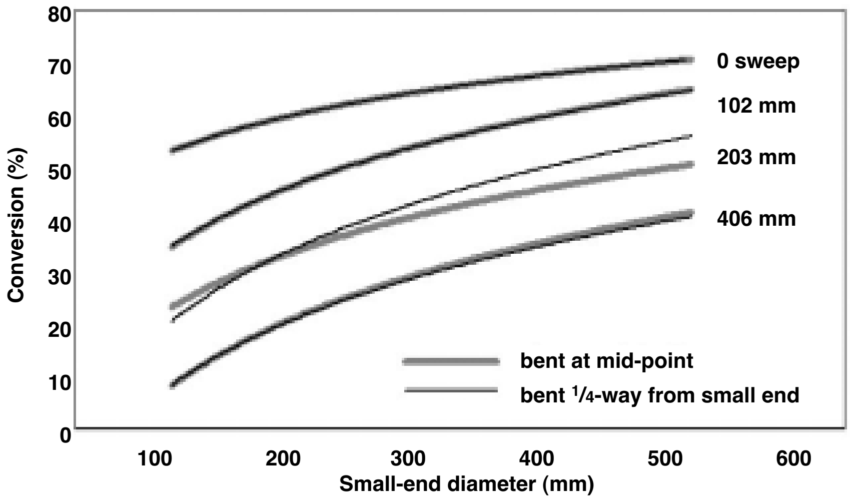

FIG. 3–Relationship between conversion and small-end diameter for four groupings of swept logs.

(8 and 16 inches) conversions reduced further to about 20–50% and 5–35% respectively. Furthermore, to recover the loss in conversion caused by a sweep deflection of 102 mm, a diameter increase of some 250 mm would be required. For example, a log with a 200-mm s.e.d. could achieve a 60% conversion if perfectly straight. However, with a 102-mm deflection, representing more than half the diameter, conversion reduces to 40%. To achieve 60% conversion with that degree of sweep deflection would require a small-end diameter measuring about 450 mm.

In addition to small-end diameter and sweep, taper influenced log conversion, and a multiple linear regression that related conversion to small-end diameter, sweep deflection, and taper for the sample of 1683 logs had an R^2 value of 0.90. Parameter estimates and standard errors are given in Table 5 for the sample ("All logs") and for each of the Log Sorts.

Conversion, examined in relation to the ratio of sweep deflection to small-end diameter, *s/d*, was nonlinear (Fig. 4) and could be described as a simple exponential decay function:

$$y = b_1 e^{-b2\, x}$$

where y = conversion (%), x = the ratio *s/d*, *e* is the base of natural logarithms, and b_1, b_2 are constants estimated through nonlinear regression analysis and presented in Table 6.

The relative loss in conversion diminished with increasing sweep to diameter ratio, rather than being a constant as reported by Dobie & Middleton (1980) and Cown *et al.* (1984). This decrease is shown in Table 7 alongside results from the aforementioned studies. The log samples used in the former study, as reported by the authors, were poorly distributed, while the latter study deployed very small sample sizes (n ≤ 12 for each sweep and diameter class) and loosely described straight logs as those with sweep less than s.e.d./4, moderately swept as those having sweep between s.e.d./4 and s.e.d./3, and severely swept as those with sweep greater than s.e.d./3. These broad classes have been equated to s/d ratios of 0, 0.2, and 0.4 respectively based on the mean small-end diameters of each sample.

TABLE 5–Multiple linear regression statistics relating log conversion (%) to small-end diameter (s.e.d.), sweep, and taper.

Log sort	Intercept	S.e.d. (mm)	Sweep (mm/m)	Taper (mm/m)	R^2
Parameter estimates					
1	18.211	0.180	–0.102	0.297	0.86
2	22.758	0.165	–0.104	0.215	0.86
3	19.959	0.151	–0.104	0.322	0.93
4	18.933	0.143	–0.097	0.194	0.91
5	36.139	0.073	–0.084	0.044	0.93
All logs	36.677	0.078	–0.096	0.128	0.90
Standard error					**DF**
1	4.863	0.034	0.003	0.065	227
2	4.117	0.023	0.002	0.045	359
3	3.550	0.014	0.002	0.065	227
4	4.708	0.017	0.002	0.052	359
5	1.038	0.003	0.001	0.015	491
All logs	0.405	0.001	0.001	0.017	1679

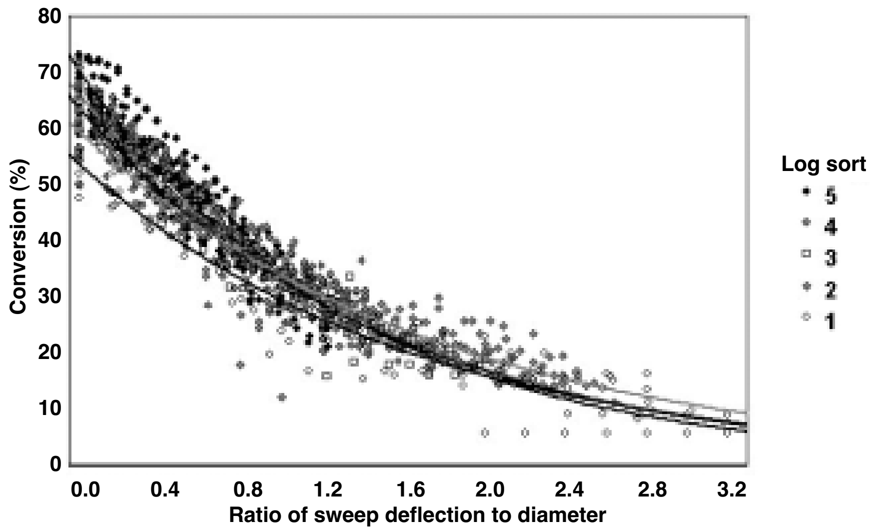

FIG. 4–Relationship between conversion and sweep to diameter ratio for all 1683 logs.

TABLE 6–Parameter estimates for exponential decay functions, $y = b_1 e^{-b_2 x}$, where x is the ratio of sweep deflection to diameter and y the conversion percentage.

Log sort	b_1	b_2	R^2	Standard error b_1	Standard error b_2
1	54.9	0.605	0.83	0.8	0.014
2	61.5	0.587	0.86	0.6	0.012
3	64.0	0.663	0.93	0.6	0.012
4	66.4	0.673	0.90	0.5	0.011
5	69.4	0.704	0.89	0.4	0.011
All logs	64.8	0.655	0.89		

TABLE 7–Comparison of conversions from various studies

Study	Conversion, $C_{s/d}$				Relative percentage decrease for each 0.1 increase in s/d		
	C_0	$C_{0.2}$	$C_{0.4}$	$C_{0.6}$	$(1–C_{0.2}/C_0)/2×100$	$(1–C_{0.4}/C_0)/4×100$	$(1–C_{0.6}/C_0)/6×100$
Dobie — Mill A*	26.6	22.8	19.0	15.1	7.1	7.1	7.2
Dobie — Mill B*	36.4	31.5	26.5	21.6	6.7	6.8	6.8
Cown — Cpt 1†	58.7	52.6	47.6		5.2	4.7	
Cown — Cpt 36†	57.2	52.1	44.5		4.5	5.6	
Log sort 1	53.7	47.6	42.2	37.4	5.7	5.4	5.1
Log sort 2	59.5	53.2	47.5	42.5	5.3	5.0	4.8
Log sort 3	63.8	55.9	48.9	42.8	6.2	5.8	5.5
Log sort 4	66.1	57.8	50.6	44.2	6.3	5.9	5.5
Log sort 5	70.4	60.7	52.4	45.2	6.9	6.4	6.0

* Kiln-dried and dressed, 15-cm-diameter class (Dobie & Middleton 1980)

† Based on mean conversion obtained from small samples ($n \leq 12$), straight logs (s/d=0) defined as those with sweep less than s.e.d./4 (mean s.e.d. = 376 cm, 409 cm for Cpt 1 and Cpt 36, respectively), moderately swept (s/d=0.2) having sweep between s.e.d./4 and s.e.d./3 (s.e.d. 404, 408), and severely swept logs (s/d=0.4) with sweep greater than s.e.d./3 (385, 389) (Cown *et al*. 1984)

Relative loss in conversion was similar for both sets of swept logs and a comparison of the 16 paired sets of 51 swept logs indicated that there was no significant difference in conversion between uniformly swept logs, bent at the middle, and the corresponding non-uniformly swept logs, bent quarter-way from the small-end of the log (Table 8). However, of the 816 log pairs, conversions differed for 120 pairs and within this sub-sample differences ranging from –8.0% to 9.1% were recorded. Differences were approximately normally distributed (Fig. 5a) but no relationships were identified between conversion differences and log characteristics (small-end diameter, sweep deflection, s/d, and taper; Fig. 5b to 5e).

TABLE 8–Mean conversions and standard deviations of each of the 51-log sets

Log bent at mid point			Log bent 1/4-way from small-end		Pair-wise comparison	
Sweep (mm)	Mean conversion (%)	Standard deviation	Mean conversion (%)	Standard deviation	P(T≤t) 95% CI*	Pearson correlation
0.0	61.5	6.4	61.5	6.4	Undefined†	1.00
25.4	60.4	6.1	60.4	6.1	0.76	0.99
50.8	56.8	6.9	56.8	7.0	0.92	0.99
76.2	53.4	7.3	53.5	7.3	0.75	0.99
101.6	49.2	9.0	49.2	9.0	0.94	1.00
127.0	45.8	10.4	45.8	10.4	1.00	1.00
152.4	43.1	10.4	43.1	10.5	0.79	1.00
177.8	39.6	11.1	39.6	11.2	0.58	1.00
203.2	37.6	10.3	37.6	10.1	0.75	1.00
228.6	35.2	10.2	35.2	10.1	0.84	1.00
254.0	33.0	10.6	32.9	10.6	0.19	1.00
279.4	31.2	10.7	31.1	10.8	0.57	0.99
304.8	29.2	10.1	29.6	9.8	0.07	0.99
330.2	28.7	9.5	28.3	9.6	0.07	0.99
355.6	26.4	9.2	26.6	9.5	0.57	0.98
381.0	24.8	9.4	24.8	9.3	0.91	1.00
406.4	24.2	9.3	23.9	9.2	0.13	0.99

* Confidence interval
† Identical samples

Lumber Grade

The change in lumber grade distributions with increased sweep deflection is shown in Fig. 6. Overall the relationship between Grade 1 lumber, consisting of Select Structural and 1 Common lumber, was best described by an exponential decay function. The same was true for Grade 2, but Grades 3 and 4 were best described as linear functions. The rate of loss in Grade 1 lumber with increasing sweep deflection over the interval from 0 to 406 mm was about 3.1%. In contrast the rate of loss in Grade 2 lumber was about 4.9%, that for Grade 3 about 1.1%, and that for Grade 4 about 0.6%, for each 100-mm increase in sweep deflection. The greatest rate of loss in volume with increasing sweep deflection was 7.2%, recorded with Grade 1 over the interval from 51 mm (2 inches) to 152 mm (6 inches).

In the comparison between uniformly and non-uniformly swept logs (Fig. 7) the grade reductions were similar when taken over the entire interval; however, within the 50.8- to

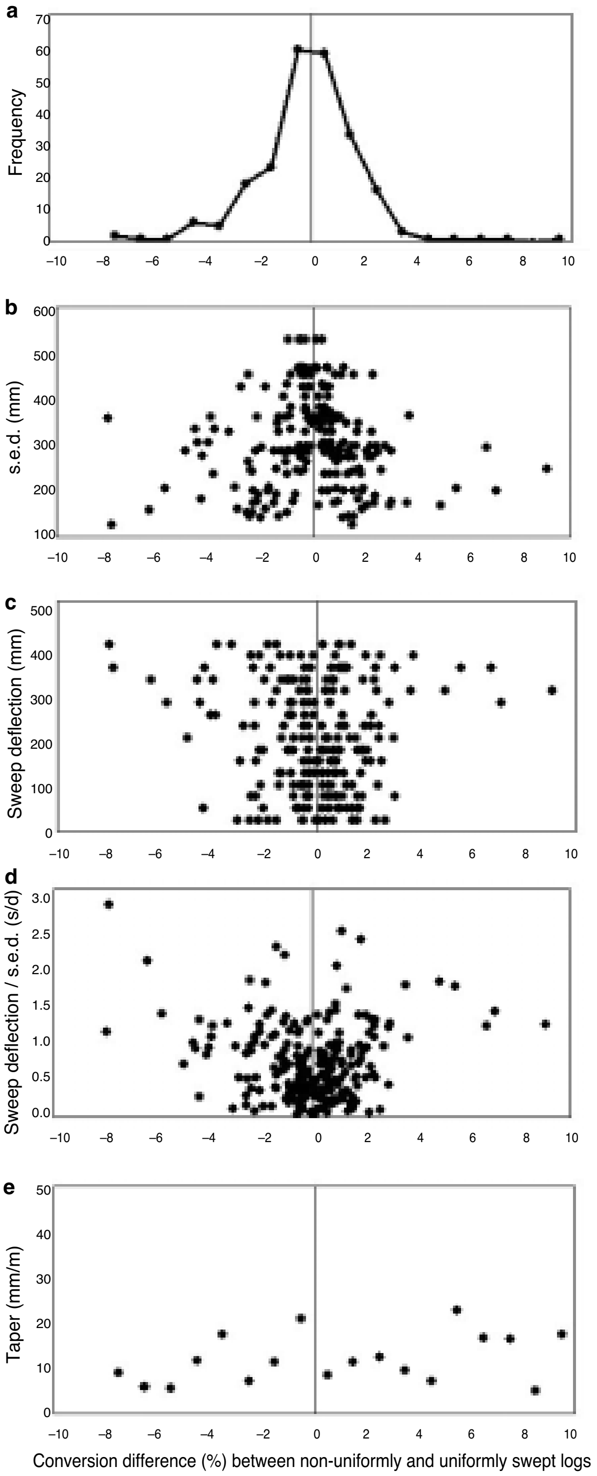

FIG. 5a–e: Conversion differences and characteristics of the 120 paired logs (bent at quarter- and half-way along the log) for which differences were recorded.

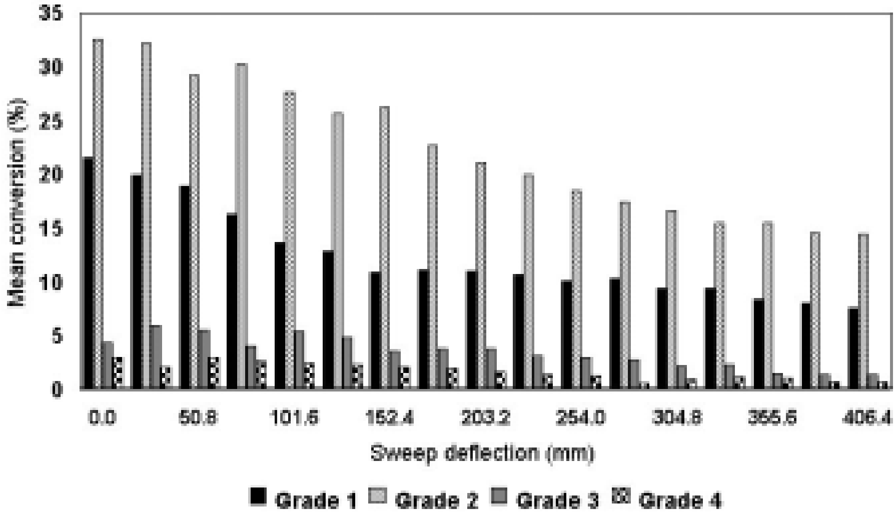

FIG. 6–Lumber grade distributions for the 16 sets of swept logs.

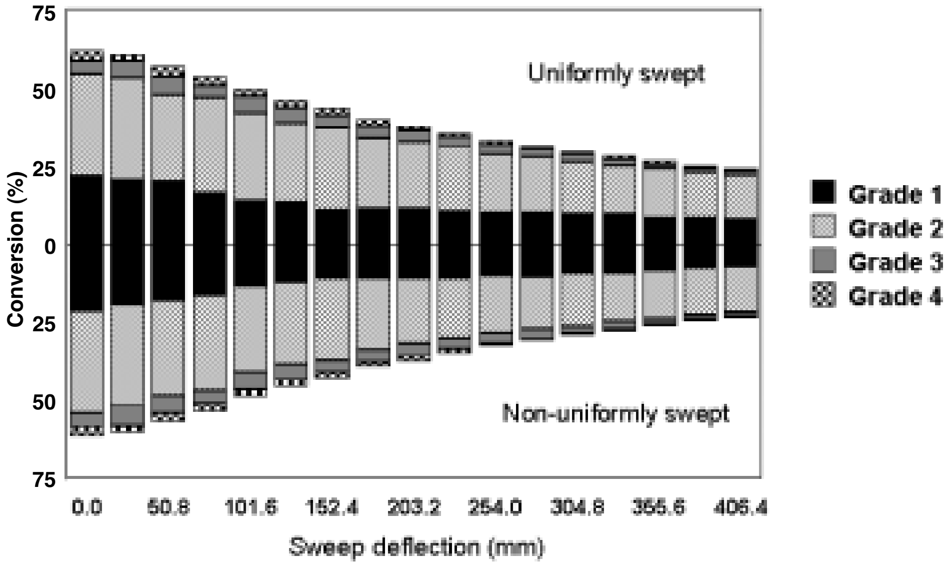

FIG. 7–Comparison of grade distributions from uniformly and non-uniformly swept logs.

152.4-mm (2- to 6-inch) interval the rate of loss in Grade 1 lumber of uniformly-swept logs was 7.9% compared to 6.9% for non-uniformly-swept logs.

Of the 816 swept log pairs, 430 pairs recorded identical distributions when grades were as defined by the 10 initial lumber grades, and 469 pairs recorded identical distributions when using the amalgamated set of four grade categories. The percentage of log-pairs recording differences increased with log sort: 19% (21 of the possible 7×16=112 paired swept logs) for Log Sort 1, 32% (56 of 176) for Log Sort 2, 46% (51 of 112) for Log Sort 3, 48% (85 of 176) for Log Sort 4, and 56% (134 of 240) for Log Sort 5.

Lumber Value

Lumber value per cubic metre of log volume was sensitive to log size and decreased non-linearly with increasing sweep deflection (Fig. 8). The gap between Log Sort 1 and 5 logs was about $30/m^3 with no sweep, $40/m^3 with 100 mm sweep deflection, and $50/m^3 with 200 mm sweep deflection. On average, a 5% loss in value, relative to that of straight logs, was recorded with a 12-mm deflection in Log Sort 1. For Log Sorts 2 to 5, the 5% loss was recorded at 12, 16, 17, 21, and 30 mm of sweep, respectively. A 10% relative loss in value was recorded when sweep deflection was 24, 34, 36, 43, and 61 mm for Log Sorts 1 to 5, respectively.

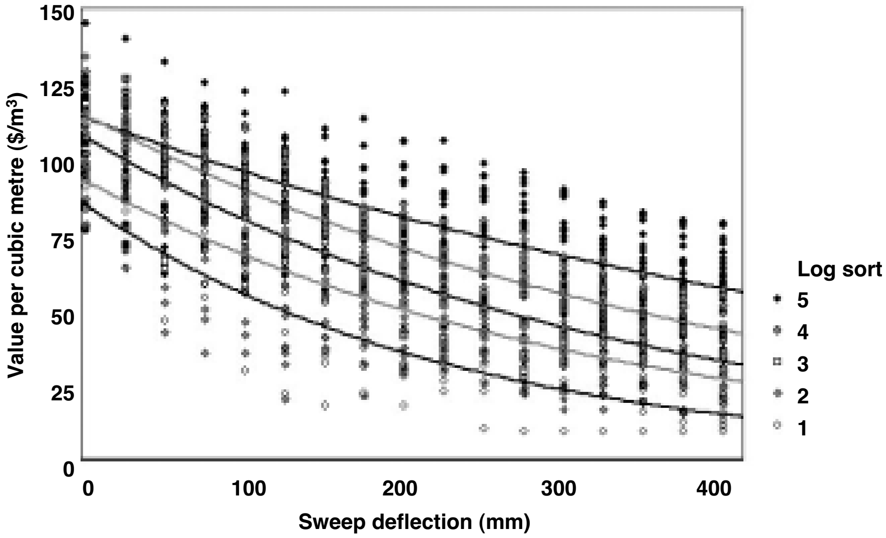

FIG. 8–Relationship between value per cubic metre (log) and sweep deflection for the 1683 logs.

DISCUSSION

The expected trend of decreasing product recovery with increasing sweep was found. The trend between conversion and the amount of sweep was strongly linear and the variation about this trend was largely due to log size (Fig. 2). Furthermore, the rate of loss in conversion with increasing sweep to diameter ratio was of the same order of magnitude (5–7%) as reported by Dobie & Middleton (1980) and by Cown *et al.* (1984). Unlike those sawing studies that reported constant rates of conversion loss, this study found the rate to diminish with increasing s/d ratio. Furthermore, the relationship between conversion and s/d ratio was described by an exponential decay function. Loss in value per cubic metre with increasing sweep deflection was also described by an exponential decay function, as was loss in the conversion to higher grades. However, conversion to lower grades declined linearly with increasing sweep.

The use of modelling tools has played an important role in determining the above relationships. Here they provided the ability to repeatedly saw the same sample of logs under identical sawing conditions, bend the logs in known magnitudes, and provide a solid basis for unbiased comparisons. In this study physiological effects, branching, compression wood, and slope of grain were not considered. All logs retained their original branching structure (number, size, shape, location at pith) regardless of the extent of sweep. The validity of this assumption is currently being investigated through analysis of pairs of swept and straight *P. radiata* clones. Compression wood is difficult to discern visually, and was not a factor in the visual grading rules used here. For the most part the lumber grade is awarded based on the presence and size of live and dead knots, and also checks, grain (ring count per inch), shake (delaminations between growth rings), slope of grain, splits, wane, and stain. Compression wood may be associated with slope of grain, which is one of the grading criteria. If excessive, then this would have a detrimental effect on lumber grade and value, which would be lower than predicted here.

The modelling approach applied here has enabled the establishment of an upper limit on lumber conversions, grades, and lumber value with increasing sweep when straight-sawing. Given the exponential decrease in value and the greater rate of loss in value for smaller logs (Fig. 8) alternative technologies such as curve-sawing, that provide a mechanism for reducing or eliminating those losses, would be beneficial.

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