Lumber Volume and Value Recovery from Small-Diameter Black Cherry, Sugar Maple, and Red Oak Logs

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While only a very small percentage of hardwood logs sawn by conventional sawmills in the U.S. have small-end diameters less than 10 in, portable and scragg mills often saw smaller logs. With the closure of regionally important oriented strand board and pulpwood operations, small-diameter logs are considered to have no value in some markets. This study was conducted to assess the volume and value of lumber produced from small-diameter hardwood logs of three important commercial species: red oak, sugar maple, and black cherry. Value assessments included determining yields for both green and kiln-dried lumber subjected to different dry kiln schedules. Volume and grade recovery from these small-diameter logs were lower than prior studies suggested. The value of recovered lumber per ft^3 of log volume was not found to be affected by log small-end diameter class for black cherry and red oak, but the value was significantly affected for sugar maple. The loss in lumber value that was attributed to kiln-dried based grade changes was greatest for red oak and least for sugar maple. For red oak, the modified dry kiln schedule did not affect the lumber value. For black cherry and sugar maple, there were kiln-schedule based differences in the value of the dry lumber recovered.

Keywords: Small-diameter hardwoods; Lumber recovery; Log grade; Lumber grade; Value

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INTRODUCTION

The standard operating procedures for merchandizing hardwood roundwood from timber harvests is to ship smaller diameter logs to a wood chipping/stranding operation for conversion into pulp, engineered wood/panel products, or wood pellets. Improved markets for small-diameter hardwoods were expected with the arrival of new oriented strand board (OSB) mills in the Southern, Mid-Atlantic, and Northeastern U.S. during the 1990s and 2000s (Bumgardner *et al.* 2000). The prospect of OSB mills creating demand for small-diameter and intermediate- to low-quality hardwood stems locally and regionally led to speculation that selection cutting systems might become more economically attractive to landowners, foresters, and loggers. However, the collapse of the housing industry in 2007 to 2009 led to the closure of several of those mills. In the Southern U.S. (Virginia to Texas), there were 17 active OSB mills in 1995 and 25 by 2005, but in 2015, only 21 mills remained (Stewart 2015). Between 2005 and 2009, the volume of OSB produced in the U.S. declined by 37%. Although production levels have been rising since 2009, by 2014 about 80% of the lost production volume has been recouped (Howard and McKeever 2012, 2015), the expectation of new OSB mills creating markets for small-diameter hardwoods has been dispelled.

The minimum sawlog size specification varies among sawmills and over time, and depends on a handful of factors, such as current sawtimber availability, sawmill size and type, species, the relative price margin between saw logs and pulpwood, and the availability of pulpwood markets in the region. Some sawmills may require larger small-end diameter (SED) logs, such as 12 inches, while SEDs as small as 8 inches may be accepted by other sawmills. Tallies of roundwood pieces shipped to sawmills and scragg mills from the log decks of 60 logging operations in West Virginia and Ohio indicate that scragg mills tend to utilize smaller logs than grade sawmills, but the percentages of SED logs smaller than 10 inches is low for both states (2% of saw logs and 33% of scragg logs in West Virginia; 2% of saw logs and 13% of scragg logs in Ohio) (Grushecky *et al.* 2011; Wiedenbeck and Grushecky 2014; unpublished data). The Ohio data collected in the Grushecky and Wiedenbeck studies provides information on the SED distribution of harvested butt logs according to the type of harvest operation. For clearcut operations, 31% of the butt logs had SEDs less than or equal to 10 in. For selection cuts, the percentage of butt logs with SEDs less than or equal to 10 in was 26%. In diameter-limit operations, this percentage was only 8%. The optimal value recovery when sawing smaller diameter hardwood logs appears to be a more relevant matter than most industry observers realize because the average SED of the sawlogs trucked to sawmills and scragg mills in the Ohio study (Grushecky *et al.* 2011) was less than 14 inches for 17 of the 29 saw/scragg mill customers and 5 of these customers actually received logs with average SEDs less than 12 inches.

Studies of lumber recoveries from small-diameter hardwood logs have not been consistent in the log diameters studied. The lack of an agreed upon definition for what constitutes a small-diameter log is due to the variability of markets and resource constraints locally, regionally, and temporally. It is not unusual to hear "small diameter" and "low grade" hardwoods lumped together when market and utilization challenges are discussed. For this reason, one could define small-diameter logs as logs with scaling diameters (small-end diameter inside the bark) of 10 inches and less since a log must have an SED of at least 11 inches to be an F2 grade (intermediate grade) log under the Forest Service log grading system (Rast *et al.* 1973).

Prior studies of small-diameter log utilization in conventional saw mill systems have addressed volume and grade potentials based on measurements of green lumber (before drying). The first of these studies was specifically focused on the difference in recovery and value for small-diameter logs derived from thinning operations *versus* those derived from harvests in mature stands (Emanuel 1983). The logs from the mature forest were exclusively upper logs, while 47% of the logs from the thinning operation were butt logs. Based on equal-sized samples of three species (red oak [*Quercus rubra*], sugar maple [*Acer saccharum*], and yellow-poplar [*Liriodendron tulipifera*]) and four SED diameters (8, 9, 10, and 11 inch), the overrun, which is based on the International ¼-in log rule, for the butt logs from the thinning operations was 19%. By comparison, for a similarly represented sample from a mature forest, the overrun was 13% (Emanuel 1983). The lumber recovery factor (LRF), which is the board feet (BF) lumber volume recovered per ft^3 of log volume, for all 120 logs in the Emanuel (1983) study was 6.75 BF/ft^3.

The value of the products sawn from these logs is a significant concern for small-diameter hardwood utilization. Value is as much a function of the grades of lumber recovered as it is volume. According to Emanuel (1983), the butt logs removed in a thinning operation produced 21% No. 1 Common and Better (1C&Btr) lumber (National Hardwood Lumber Association 2004), while the small-diameter logs derived from both butt and upper logs from a mature forest yielded a lower grade distribution of 11% 1C&Btr. These 1C&Btr percentages are lower than those determined in the comprehensive set of sawmill studies carried out over 40 years by Hanks *et al.* (1980), which provides the foundation of the log grade–lumber grade yield valuation system. For red oak, sugar maple, and yellow-poplar, the yields of 1C&Btr lumber recovered from Grade 3 logs from all log diameter classes, as opposed to only 8 to 11 in logs, were 29%, 23%, and 26%, respectively (Hanks *et al.* 1980). The quality of the lumber sawn from the logs removed in the thinning operation appears to be comparable to the data obtained by Hanks *et al.* (1980), but the small-diameter logs from the mature forest appear to yield lumber of inferior quality (Emanuel 1983).

A second more recent study of the lumber yields from small-diameter logs of unspecified tree species looked at recovery differences based on the degree of log sweep and the type of sawing process used (straight *versus* curve sawing) (Hamner *et al.* 2006). The average SED for the 134 logs in the Hamner *et al.* (2006) study was 9.8 in. The average LRF for the group of logs with minimal amounts of sweep (0% to 15%) was 7.47 and the average overrun was 34% (International ¼-in log rule basis). All recovery figures included the recovery of a 4x6 or 4x8 inch cant from the center of all logs. Lumber grades were not evaluated in the Hamner *et al.* (2006) study nor were the species reported.

A third small-diameter recovery study analyzed lumber and pallet/container part yields from red oak logs sawn using a scragg saw-gang resaw system with the resaw set to produce a 3-inch thick cant and 4/4 (1 in) in thick lumber when feasible (Perkins *et al.* 2008). The cant was then processed into pallet/container parts. Of the lumber produced, 24% was graded as 1C&Btr. The overrun, based on lumber and cant volumes recovered, was 14% (International ¼-in basis) for logs ranging from 6 inch to 10 inch SED (Perkins *et al.* 2008). However, 64% of the solid wood volume recovered was 3-inch thick cants with only 36% being 1-inch thick grade lumber.

Of the three studies outlined above, the Emanuel (1983) study sawed entire logs into 1-inch-thick lumber, while the Hamner *et al.* (2006) and Perkins *et al.* (2008) studies recovered both 1-inch-thick lumber and cants (3 and 4 inch thick).

Lumber for high-value appearance products must be dried to a moisture content that suits the interior environment where the final product will be located. Usually this means it must be kiln-dried to a moisture content of 8% to 10%. The stresses that arise during the drying process frequently lead to defects in the lumber that reduces its grade, value, and utility. When assessing the potential for using smaller diameter hardwood logs in the manufacture of hardwood lumber, the quality and value of the kiln-dried lumber is the ultimate measuring stick to be used.

Scholl *et al.* (2008) reported on the lumber grade yields and other quality characteristics of black cherry (*Prunus serotina*) lumber sawn from small-diameter logs and dried in a kiln. This study identified defects and grade/value losses that arose during kiln drying, with both a conventional black cherry kiln schedule and two alternate schedules. Scholl (2006) evaluated recoveries from small-diameter red oak and sugar maple logs, as well as black cherry. For all three species, a broad spectrum of utilization attributes was measured, both before and after kiln drying.

The overarching objective of the research presented here is to develop data on the quality and value of lumber produced from small-diameter hardwood logs of three important commercial species, red oak, sugar maple, and black cherry. No other study has addressed these three species, included value considerations, and looked at grade and value losses for lumber sawn from small-diameter logs after the lumber is kiln dried.

EXPERIMENTAL

Log Samples

The log samples were obtained from small-diameter trees harvested in northern and central Pennsylvania. The sample was a convenience sample – an unavoidable situation when working with forest businesses that can afford to donate only very limited resources to a study. Logs were provided by cooperating sawmills and were delivered to the collection/processing site over a period of weeks. All stems delivered to the study team were included in the sample. The stems were of varied lengths when received, and were then bucked into 8-ft 4-in lengths, numbered for tracking purposes, and end-sealed. One or two 8-ft logs were obtained from each stem. The overall sample consisted of 159 logs from 130 black cherry trees, 132 logs from 113 sugar maple trees, and 87 logs from 70 red oak trees. In the cases in which a second log was obtained from a delivered roundwood stem, the logs were treated as independent samples. The black cherry samples had the greatest percentage of logs with SEDs less than 10 in, 63%. The percentage of logs in the sugar maple and red oak samples that were less than 10 in were 31% and 40%, respectively.

The grade of the logs was assessed before sawing. Log grade distributions were reflective of the Forest Service hardwood log grading rules (Rast *et al.* 1973), which specified the minimum log SEDs for three defined "factory" grades, F1, F2, and F3. For log grade F1, the minimum SED for the highest quality log is 13 inch. There were no F1 logs in the received sample for any species. For the next best grade, F2, the best quality log must have a SED of at least 10 inch, but generally, logs must have 11-inch SEDs. The black cherry, sugar maple, and red oak log samples each contained only a very small percentage of grade F2 logs – less than 3%. Forest Service grade F3 logs must have an SED of at least 8 inch and meet other quality specifications. All logs that were smaller than 8-inch SED or of especially poor quality (Rast *et al.* 1973) were considered to be Below Grade (classified as grade F4). Aside from the few F2 logs, the remainder of the black cherry log samples were F3 (75%) and F4 (24%). The proportion of F3 and F4 for the sugar maple logs was 50% and 49%, respectively. The red oak samples were an anomaly, with 96% of the red oak logs grading F3. This was reflective of the SED requirements of the Forest Service log grading rules (Rast *et al.* 1973), as indicated by the red oak SED distribution shown in Fig. 2.

Log Breakdown and Lumber Quality Assessment

Logs were grade or live sawn using a portable sawmill. Log straightness (sweep and crook) was used to determine if the log would be grade or live sawn. The desire was to grade saw all logs for which it was reasonable to do so. However, logs containing sweep/crook could not be effectively rotated on the portable mill as is done in grade sawing (Fig. 1 on left depicts a grade sawing pattern) so they were live sawn (all saw lines oriented parallel to each other). For both sawing patterns, the opening face was the face opposite the best log face. Before sawing, a stencil was used to mark log ends with paint to demarcate three "quality zones" (Fig. 1), which are the core center (radius equal 20% of log diameter), and the inner and outer quality zones, as defined in Rast *et al.* (1973). As boards were generated by the mill, log numbers were transferred to boards and board numbers were assigned for further tracking. Boards were edged, as needed. A pre-drying inspection of the lumber was conducted within 24 hours after sawing and just prior to loading the lumber into the dry kiln. End checks, surface checks, shake, bow, twist, crook, and cup were documented on each board. Green lumber grades were determined at this point as well.

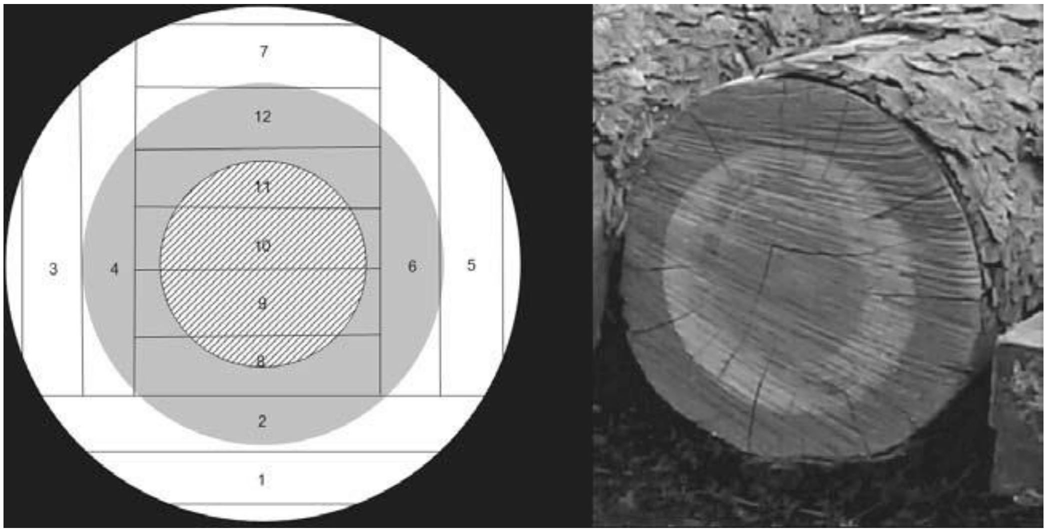

Fig. 1. Quality zones demonstrated (left) and painted onto black cherry log in this study (right) as defined in Rast *et al.* (1973)

Kiln Drying

Lumber was hand stacked into packs that were 8 ft long x 4 ft wide x 4.5 ft high. The kiln used was a steam kiln with a capacity of 1,500 BF. Because this was a small, well-maintained, experimental dry kiln, temperature and airflow variations were minimal. All lumber sawn from a given log was dried in the same dry kiln charge (batch). When possible, boards sawn from logs originating from the same supplier were distributed among kiln charges. For each species, a conventional kiln schedule (Dry Kiln Operator's Manual 2001) and two experimental kiln schedules were used during the study. Drying rates were monitored closely with 4-6 kiln samples per 1,500 bf kiln charge. During the sawing stage, it became apparent that the heartwood of the red oak logs/lumber was bacterially infected (BI). This condition is not uncommon. The BI red oak must be dried more carefully to prevent deep surface checks, honeycomb, and ring failure (USDA 1987). A BI red oak dry kiln schedule was given in the Dry Kiln Operator's Manual (2001) and was incorporated into this study as the "conventional" schedule for red oak. In total, 10 kiln charges of lumber sawn from small-diameter logs were processed and analyzed.

Post-Drying Inspection and Recovery Calculations

After kiln drying was completed, the lumber was inspected again for defects and grade. The surface measurement used to calculate the green grade was used to determine the dry grade. By standardizing this, the effects of the kiln drying process on the occurrence of drying defects were unmasked. Each of the original cuttings, which had been marked on the boards prior to drying, was evaluated for defects and dimensional changes that would potentially lower the board grade.

Data analysis included calculating the over/under-run, LRF, the green lumber value recovery per ft^3 of log volume, the dry lumber value per ft^3, and the change in lumber value per ft^3. Additionally, to allow for a direct comparison with the Emanuel (1983) results, overrun and LRF also were calculated for the subset of logs that were Grade 3, which are 8 to 11 in SED within each species. LRF and over/underrun were calculated for each log according to Eqs. 1 and 2,

$$\text{LRF} = \frac{Total\ bf\ lumber\ recovered\ from\ log}{\log volume\ (ft3)} \tag{1}$$

$$\text{Over/underrun} = \frac{(Total\ bf\ lumber\ recovered\ from\ log - bf \log volume[International 1/4-inch])}{\text{bf} \log volume} \tag{2}$$

Lumber prices were based on the average green lumber prices, by species, and lumber grade (National Hardwood Lumber Association 2004), and were obtained from the Hardwood Market Reports dated June 5 and December 18, 2015 (Hardwood Market Report 2015a; Hardwood Market Report 2015b). Appalachian pricing was used. Prices for Selects & Better lumber were based on the proportional representation of FAS, FAS-1F, and Selects grade lumber recovered by species. Prices for No. 2 Common lumber were based on the proportional representation of No. 2A and 2B lumber recovered. Prices for No. 2B Common lumber were not available for the three species in this study, so 4/4 in thickness was multiplied by Random Width pallet lumber prices and that was used instead (upper end of price range given). Prices were available for No. 3A Common lumber, but No. 3B prices were not. For No. 3B, the price applied was the lower end of the pallet part price range cited in the two price reports. The pallet part prices used for No. 2B and No. 3B Common lumber were consistent across species ($317.50 and $252.50). The lowest grade of lumber tallied in the study was called “outs.” A very low value, $50/MBF, was used for this material. This value was assigned without verification, as no pricing information was available. These same prices were used for the dry lumber evaluation so that the green and dry lumber values could be directly compared.

Statistical Analysis

Lumber volume and value recovery models

Statistics were conducted using SAS Enterprise Guide 6.1 (SAS Institute, Cary, NC, USA). Analysis of variance (ANOVA) was conducted ($\alpha = 0.05$) using the PROC GLM procedure (for unbalanced designs). First, tests were conducted on measures of green lumber recovery, which is LRF and green lumber value recovery per ft^3 (\$/ft^3) of log volume. Due to the small sample sizes in some of the log SED classes (Fig. 2, Table 1), the log size was classified as a nominal explanatory variable with two classes in this analysis, SED less than 10 inch and SED greater than or equal to 10 inch. Similarly, the number of grade F2 logs sawn in the study was very small for all three species, and for red oak, the sample of grade F4 logs also was very small, with only one log (Table 1). Therefore, for black cherry and sugar maple, the log grades were grouped into two classes, F2&F3 and F4. For red oak, log grade was not used as a classification variable in the analyses.

$$\text{Model: } Y_{ijk} = \mu + \alpha_i + \beta_j + \alpha_i \times \beta_j + E_{ijk} \tag{3}$$

In Eq. 1, Y is the LRF or green/dry lumber value per log ft^3, μ is the overall mean, α_i corresponds to the effects associated with the i-th level of SED class, β_j corresponds to the effects associated with the j-th level of log grade class, $\alpha_i \times \beta_j$ represents the interaction effect for the i-th level of SED and the j-th level of log grade, and E_{ijk} is an error term (unexplained variation).

Table 1. Log and Lumber Sample Sizes for Each Species, Small-End Diameter (SED) Class, and Log Grade Class Group

Species	Log grade[A]	F2&F3	F4	All grades	F2&F3	F4	All grades
	SED	(no. of logs) [%]			(no. of boards) [%]		
Black cherry	< 10 in	76	24	100 [63]	472	111	583 [57]
	≥ 10 in	53	6	59 [37]	413	33	446 [43]
	Total	129 [81]	30 [19]	159 [100]	885 [86]	144 [14]	1029 [100]
Red oak	< 10 in	34	1	35 [40]	236	6	242 [36]
	≥ 10 in	52	0	52 [60]	431	0	431 [64]
	Total	86 [99]	1 [1]	87 [100]	667 [99]	6 [1]	673 [100]
Sugar maple	< 10 in	14	27	41 [31]	83	122	205 [21]
	≥ 10 in	64	28	92 [69]	557	215	772 [79]
	Total	78 [59]	55 [41]	133 [100]	640 [64]	337 [36]	977 [100]

[A]-F2, F3, and F4 refer to Forest Service Factory Lumber log grades (Rast *et al.* 1973).

A third analysis (dependent) variable of interest in considering the effects of log diameter and log grade on overall lumber volume and value recovery was the value of the dry lumber recovered from logs. Multi-factor ANOVA test procedures were run, which were similar to those used in looking at green lumber recovery results.

For each of these tests, the Anderson-Darling test of normality was conducted to assess the underlying assumption of normality. Residual plots were used to further assess the normality (histograms and normal probability plots) and variance equality (box plots and Cook's D) assumptions. The assumption of normality was supported for all three species for the examination of lumber recovery factor (LRF) with all Anderson-Darling *p*-values >0.05. Tests of the distributions for green and dry lumber value per cubic foot of log volume less consistently supported the assumption of normalcy. For both black cherry and sugar maple, one-half of the tested distributions returned *p*-values <0.05. However, with sample sizes of 27, 64, 53, and 76 for these four distributions, the multi-factor ANOVA was considered to be sufficiently robust to proceed. For red oak, the value results appeared to conform with the normal distribution assumption.

Because the analysis of variance was a multi-factor ANOVA (GLM procedure in SAS) for two of the three species (red oak was the exception), standard statistical tests for variance equality could not be used. For red oak, Levene's test of variance equality was used. The box plots and Levene's test statistic for the one-way ANOVA for red oak using only SED class as a classification variable indicated that the assumption of variance equality was not justified. Subsequently, the relationships between LRF and lumber value per ft^3 and SED class for red oak were evaluated using Welch's ANOVA, which is robust for one-way ANOVA in which variance heterogeneity exists.

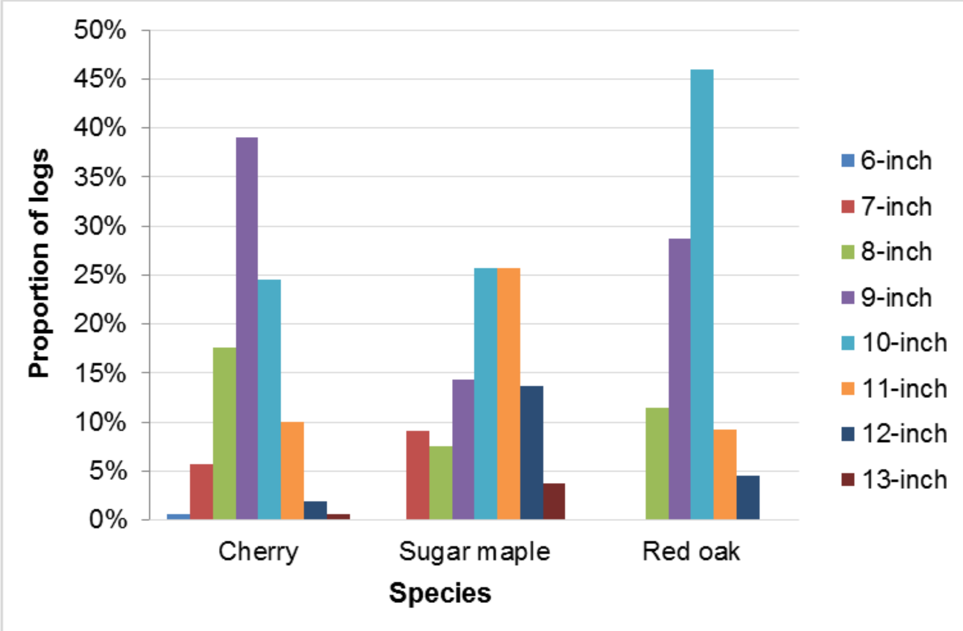

Fig. 2. Distribution of log SEDs by species

RESULTS AND DISCUSSION

Log Breakdown and Lumber Quality Assessment

Overall, 80% of the logs in the sample (n = 379) were grade sawn, with the following breakdown by species: black cherry – 81%, sugar maple – 77%, and red oak – 82%. Twenty-six percent of the lumber recovered was sawn from the core center, 35% was from the outer quality zone, and 38% was from the inner quality zone. The average ages of the trees that were harvested for this study were 58, 69, and 78 years for black cherry, sugar maple, and red oak, respectively. Eighty-five percent of the sawn black cherry logs were butt logs. The butt log proportions for the sugar maple and red oak log samples were 90% and 80%, respectively.

The mean LRF for the small-diameter logs from all three species sawn in this study was 6.5 (BF of lumber recovered per ft^3 volume of log). For black cherry, sugar maple, and red oak, the mean LRFs were 6.08, 6.38, and 7.45, respectively. The LRF summary results are depicted in Fig. 3.

The black cherry and red oak results shown in Fig. 3 suggested that the recovery of lumber from logs with SEDs less than 10 inch was higher than for the logs with SEDs greater than or equal to 10 inch. For sugar maple, this appeared to also be true for the F2&F3 logs, but not for the F4 logs.

As predicted by the Forest Service log grading rules (Rast *et al.* 1973), the mean LRFs for logs graded F2&F3 are higher than for the grade F4 logs for both black cherry and sugar maple. The half-width standard error bars indicated that the volume of lumber recovered from the F4 logs was more variable than for the lumber recovered from the F2&F3 class of logs. Only one grade F4 log was sampled for red oak, therefore only the F2&F3 results were presented for this species.

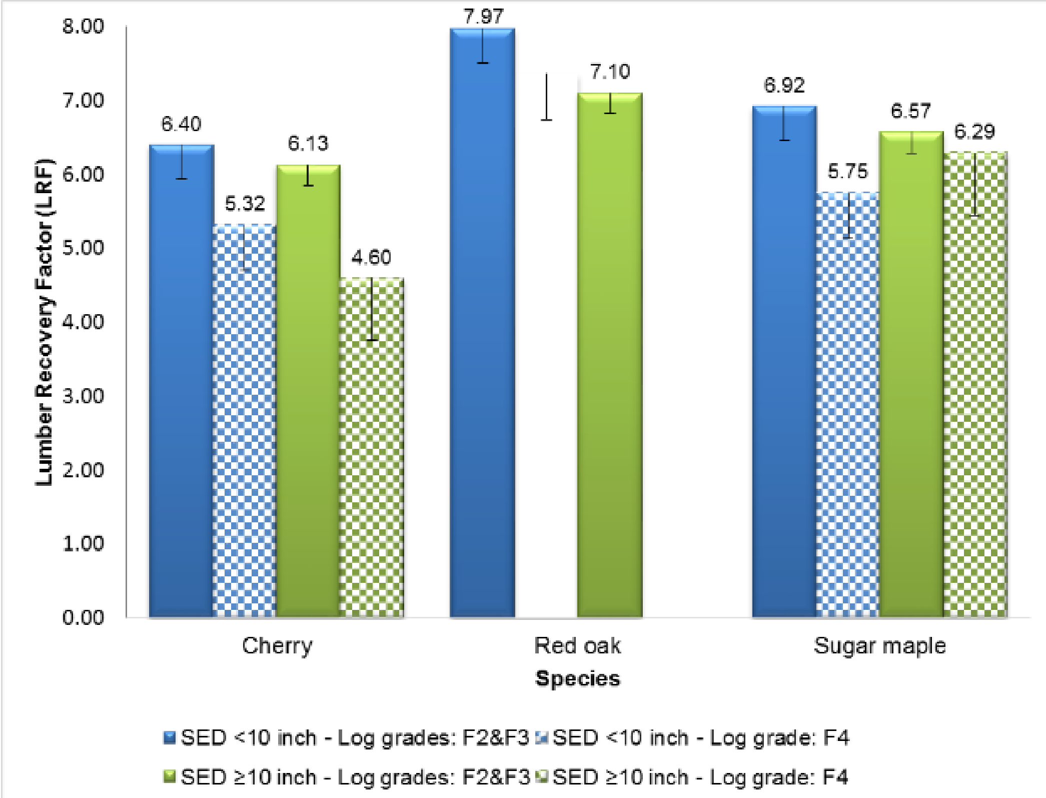

Fig. 3. LRF percentages (BF of lumber recovered/cubic foot of log), with half-width standard error bars, by species, log grade class, and SED class

Comparing these LRF results to those of Emanuel (1983) showed that higher LRF recovery was achieved in this study for red oak (7.4 *vs.* 6.6 BF lumber per ft^3 logs). The sugar maple LRF was lower in this study compared to the Emanuel (1983) study, 6.4 and 6.7, respectively. The size of the small-diameter red oak and sugar maple samples sawn in this study were 5.3 and 3.5 times the size of the samples studied by Emanuel (1983), respectively. The overall mean LRF obtained in this study was 6.6. Conventionally sawn logs in the Hamner *et al.* (2006) study yielded an average LRF that was somewhat higher, 6.9. A mix of unspecified tree species was examined in Hamner *et al.* (2006).

To allow for comparisons with previous studies that investigated green lumber recoveries from small-diameter hardwood logs, the over/underrun percentages were calculated and summarized. These results are shown in Fig. 4. The overrun percentages for the F2&F3 logs in the smallest diameter class (< 10 in SED) were 2%, 30%, and 10% for black cherry, red oak, and sugar maple, respectively. For all log diameters and grades sawn in this study, the overrun percentages were -5.3%, 12.9%, and -4.0% for black cherry, red oak, and sugar maple, respectively.

Overrun-based recovery in this study was lower than reported by Emanuel (1983) for small-diameter logs sawn from “mature” stands. In this study, the average for the three species was 4.7%, which was lower compared to 13.5% in the Emanuel (1983) study. The red oak overrun results were not very different between the two studies (13.7 for Emanuel (1983) *vs.* 12.9 for this study). However, the sugar maple overrun results were disparate with the current study’s overrun. The overrun was almost 16% lower than previously measured by Emanuel (1983).

Some of the difference can be attributed to the fact that a large percentage of the sugar maple logs in this study were Below Grade logs, while none of the logs in the earlier study were Below Grade. Below Grade logs were included in this study because there was an interest in determining the feasibility of sawing 6 and 7 in diameter logs, as well as lower quality second logs (uppers) from slightly larger trees. To make the comparison between the two studies more meaningful, the overrun results for only the 8 through 11 in Grade 3 logs in the current study were examined. For red oak, the resulting overrun was 15.3%. The overall overrun result for this subset of sugar maple logs was -1.7%, which was still considerably lower than measured in the Emanuel (1983) study. Given the current study's sample size was 5 times larger than the earlier study, the lumber recovery expectations from small-diameter sugar maple logs should be more aligned with the results of this study.

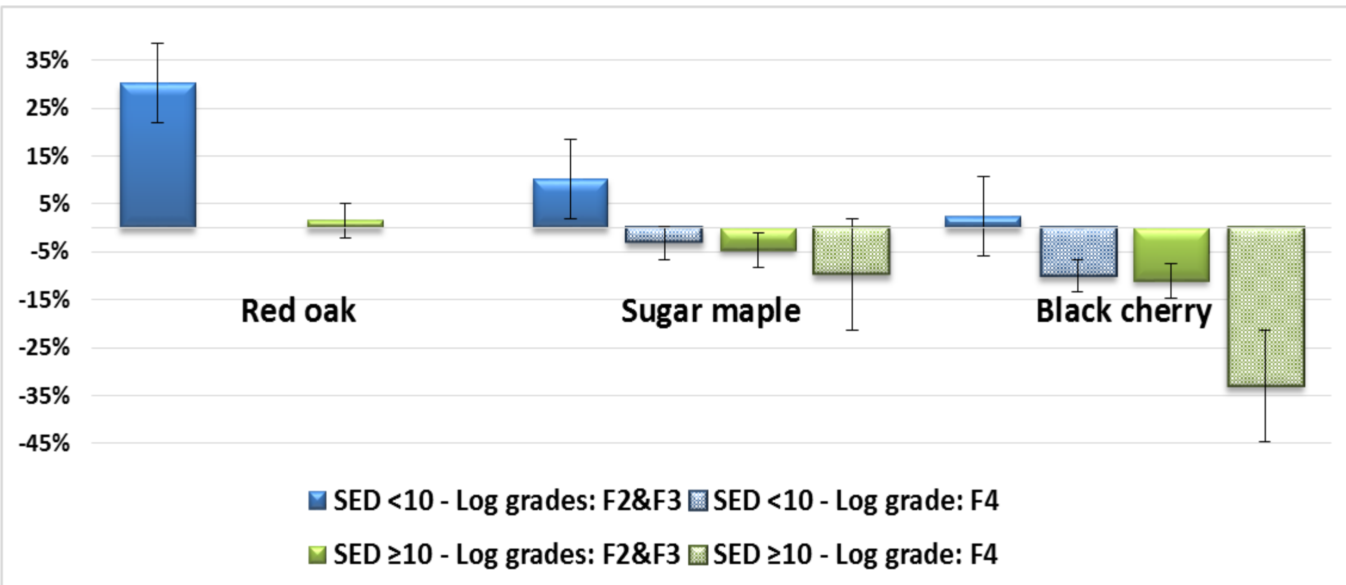

Fig. 4. Over/underrun percentages based on International 1/4-inch log scale with standard error bars by species, log grade class, and SED class

More than half of the boards recovered from the small-diameter logs in this study were low-grade boards, No. 3A or 3B Common or below. This was true for all three species and for the lumber grade proportions tabulated both before and after the lumber was kiln dried (Table 2). The increase in the absolute percentage of low-grade boards after kiln drying was about 11% across species compared to the averages from before kiln drying (Table 2).

For black cherry and sugar maple, the increase in low-grade lumber was largely attributable to the No. 2A and 2B Common green lumber losing grade in the dry kiln. For red oak, a substantial drop in the absolute percentage of No. 1 Common boards occurred during drying (Table 2). The percentage of all black cherry boards that suffered a loss in grade was 26%. For sugar maple and red oak, the percentages of boards that dropped in grade were 25% and 36%, respectively.

Table 2. Lumber Grade Proportions for Each Species and Kiln Schedule, Before and After Kiln Drying, Based on Board Counts Including Absolute and Relative Changes in Grade Proportions

Species	Lumber grade	Green lumber	Dry lumber	Absolute grade change	Relative grade change
		(%)		(%)	
Black cherry	Selects & Btr.[A]	3.1	2.4	-0.7	-22.6[B]
	No. 1C	4.8	3.3	-1.5	-31.2
	No. 2A & 2B	25.2	17.6	-7.6	-30.2
	No. 3A & 3B	60.4	67.9	+7.5	+12.4[C]
	Below Grade	6.5	8.8	+2.2	+32.2
	Sample size: n = 523 boards				
Red oak	Selects & Btr.	7.6	4.5	-3.1	-40.8
	No. 1C	14.0	6.7	-7.3	-52.1
	No. 2A & 2B	27.0	23.6	-3.4	-12.6
	No. 3A & 3B	50.6	60.0	+9.4	+18.6
	Below Grade	0.8	6.2	+5.4	+675.0
	Sample size: n=356 boards				
Sugar maple	Selects & Btr.	4.8	4.1	-0.7	-14.6
	No. 1C	6.3	3.8	-3.8	-60.3
	No. 2A & 2B	23.5	18.2	-5.3	-22.6
	No. 3A & 3B	62.1	66.7	+4.6	+7.4
	Below Grade	3.3	7.2	+3.9	+118.2
	Sample size: n = 326 boards				

[A]Selects & Btr. includes the three highest grades of hardwood lumber: FAS, FAS-1F, and Selects

The proportions of the sawn lumber recovered in this study that were Grade 3A, Grade 3B, or Below Grade (*i.e.* "low-grade boards") were higher than in the Emanuel (1983) study. For red oak and sugar maple, the overall low-grade lumber proportions in this study were 17% and 30% higher than in the Emanuel (1983) study (Table 2), respectively. The Perkins *et al.* (2008) study results indicated that the low-grade lumber proportions recovered from small-diameter red oak logs were near 50%, which was similar to the low-grade lumber proportion realized in this study. The Hamner *et al.* (2006) study did not evaluate lumber grades.

The most noted study of hardwood lumber recoveries is the long-term study summarized by Hanks *et al.* (1980). This study provided expected lumber volume and grade yields for 16 tree species by log size (scaling diameter) and log grade. The study was based on sawmill recovery studies conducted over 40 years at more than 75 sawmills. In total, about 20,000 logs were sawn and studied. The Hanks *et al.* (1980) study, like the Emanuel study (1983), gave a reference point for comparison for the 8-inch and larger SED logs in this study. The 6- and 7-inch diameter logs were not included in Hanks *et al.* (1980), as these smaller diameter logs were not considered to be of value as sawlogs and were not included as U.S. Forest Service Grade 3 logs when the grading system was established.

In Table 3, the Hanks *et al.* (1980) results for 8- and 9-inch SED logs for northern red oak, sugar maple, and black cherry are given in a side-by-side comparison with the same size and grade logs sawn in this study. The Hanks *et al.* (1980) numbers were based on air-dried (18% to 22% moisture content) lumber, while the grade distribution results from the Scholl (2006) study were for kiln-dried lumber. Table 3 shows that the lumber grade distribution recovered in this study was lower than realized in the Hanks *et al.* (1980) study. In the case of black cherry, the Hanks *et al.* (1980) results were the only comparative results available. The number of Grade F3 black cherry logs in the 8- and 9-inch diameter classes in the current study was comparable to the sample sizes from Hanks *et al.* (1980) (Table 3).

Table 3. Comparison between Lumber Grade Proportions and International ¼-inch Rule Overrun Results for 8- and 9-inch SED, Grade F3 LOGS, for Hanks *et al.* (1980) and Scholl (2006)

Species	Study	SED (in)	No. logs	Overrun – Int. ¼-in rule	Grades of lumber recovered			
					Selects & Btr.	No. 1	No. 2A & 2B	No. 3A & 3B
				(%)	(%)			
Red oak	Hanks[A]	8	24	11.0	3.1	4.9	27.7	64.3
	Scholl[B]		10	35.2	6.7	5.7	23.4	64.1
	Hanks	9	40	16.1	2.6	12.6	35.8	49.0
	Scholl		24	22.3	2.2	7.4	24.5	65.9
Black cherry	Hanks	8	34	12.3	2.3	4.2	29.7	63.8
	Scholl		23	14.9	2.8	3.2	10.2	83.9
	Hanks	9	52	8.5	3.2	10.1	36.4	50.3
	Scholl		51	-5.2	1.8	2.9	22.1	73.1
Sugar maple	Hanks	8	20	10.0	2.1	6.0	26.1	65.8
	Scholl		6	-1.0	0.0	0.0	8.2	91.8
	Hanks	9	79	9.8	2.6	10.6	21.1	65.7
	Scholl		8	18.1	0.1	1.3	13.6	84.2

[A] Hanks refers to Hanks *et al.* (1980) – NHLA lumber grade percentages are for lumber that has been air dried to 18% to 22% moisture content.
[B] Scholl refers to Scholl (2006) – NHLA lumber grade percentages are for lumber that has been kiln dried to 6% to 9% moisture content.

It is ambiguous why the recovery of the mid-grades of lumber (No. 2A and 2B Common in particular) was distinctly lower in this study, while the recovery of the lower grades was about 20% higher. In the Hanks *et al.* (1980) study, the lumber grades were assigned or estimated for air-dried lumber, whereas this study assessed kiln-dried lumber grades. It is known that the higher temperatures associated with kiln drying can lead to higher levels of checking, splitting, and shake formation compared to a well-managed air drying operation (Wengert 1990). Shrinkage is an important factor that would impact the grade yield results in this study as compared to grade results for lumber that is only dried to about 20% moisture content. As indicated in Scholl (2006) and Scholl *et al.* (2008), many of the grade lowering defects were shrinkage and split-type defects.

While this study was a controlled study in which the logs were all sawn on the same saw, very little is known about where the logs included in the tables compiled by Hanks *et al.* (1980) originated from, nor is it known how and when they were sawn and dried. They may have largely been produced by a single sawmill, or they may have been sawn by more than a dozen sawmills. It is possible that Hanks *et al.* (1980) represents a more diverse sample than the sample evaluated in this study. Another difference between the studies is that the sawmill study conducted by Hanks *et al.* (1980) cut thicker lumber (up to 4-inch thick), while all lumber cut in this study was 1-inch thick. Cutting thicker lumber from the center of logs can serve to bury the lowest quality wood that is immediately proximal to the pith inside a piece of lumber and at the same time restrain/balance drying related stresses that are particularly severe nearest the pith. This point was supported by Fig. 5, which showed that the core center of the small-diameter logs in the current study yielded 85% Below Grade and No. 3A&3B lumber, which is collectively known as “low grade lumber”. In a typical sawmill operation, the core center is not sawn into 1-inch thick boards, but instead kept together as a thicker cant.

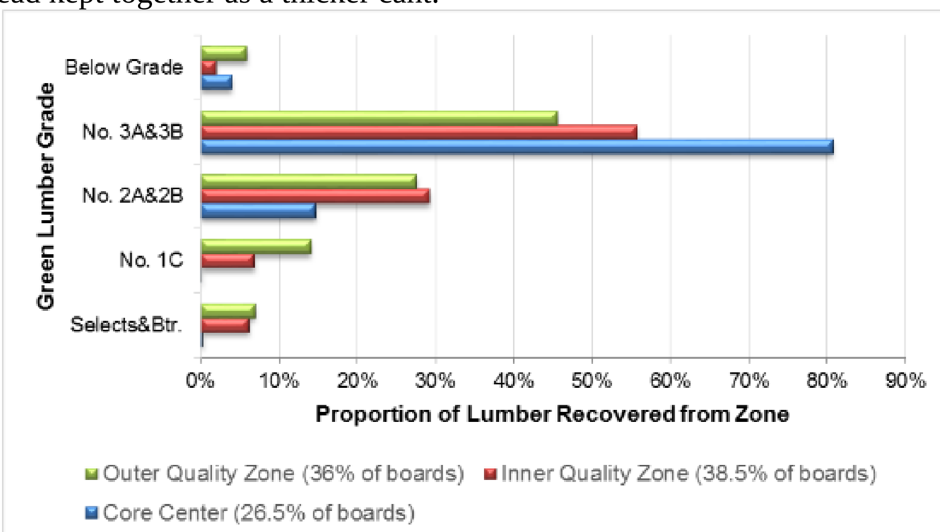

Fig. 5. Grade distribution of green lumber recovered from each of the log quality zones for all three species combined

Table 2 includes the relative percentage grade change results (change in grade percentage per green grade percentage). By looking at the relative results, it quickly became evident that the red oak lumber quality after kiln drying suffered a more substantial downgrade than the black cherry and sugar maple lumber. The presence of BI red oak in the log sample received for this study was likely a major factor that contributed to the red oak’s quality decline in drying. Increased rates of check and shake occurrence are known to occur when boards containing bacterial infection are kiln dried (Wengert 1990).

The combined effect of the lumber volume and quality recovered from these small-diameter logs was captured by looking at the value of the lumber products recovered. Differences that were identified in the diameters and grades of the logs from which the lumber was sawn were attributes of interest when trying to understand the potential utility of these logs. The pre-drying lumber value recovery per unit volume of log averaged approximately $1/ft^3 more for red oak than it did for sugar maple and black cherry (Table 4). The loss in total lumber value recovered per unit of log input after drying averaged 5.7% for the three species with the greatest percentage-based value loss measured for black cherry (Table 4). Diameter and log grade class itemizations of green and dry lumber value results found are in Table 4 and provided insight into the influence of these factors. The loss in value for sugar maple lumber after it was kiln dried was not as high as for black cherry and red oak when considering all dry-kiln treatment outcomes.

Table 4. Value of Lumber Recovered from Small-Diameter Logs Before and After Kiln Drying by Species, Log Grade Class, and Small-End Diameter Class and Percent Value Decline for All Log Grades Post Drying

Species	Log grade[A] SED	Green Lumber Value			Post-drying Loss in Lumber Value		
		F2&F3 ($/ft³)	F4 ($/ft³)	All log grades ($/ft³)	F2&F3 ($/ft³)	F4 ($/ft³)	All log grades ($/ft³) / (%)
Black cherry	< 10 in	2.47	1.88	2.33	0.14	0.14	0.14 / (6.0)
	≥ 10 in	2.59	1.50	2.48	0.22	0.05	0.20 / (8.1)
	All SEDs	2.52	1.81	**2.38**	0.17	0.13	**0.16 / (6.7)**
Red oak	< 10 in	3.72	2.69	3.69	0.22	0.00	0.21 / (5.7)
	≥ 10 in	3.43	-	3.43	0.21	-	0.21 / (6.1)
	All SEDs	3.54	2.68	**3.53**	0.21	0.00	**0.21 / (5.9)**
Sugar maple	< 10 in	2.57	1.70	2.00	0.05	0.02	0.03 / (1.5)
	≥ 10 in	3.03	2.58	2.89	0.19	0.12	0.17 / (5.0)
	All SEDs	2.95	2.15	**2.62**	0.16	0.07	**0.12 / (4.6)**

Hanks and Peirsol (1975) compiled lumber value change results for 10 hardwood species included in the Hanks *et al.* (1980) study. The study summarized value loss associated with air drying and included northern red oak and sugar maple. The value losses associated with changes in lumber grade (not those associated with changes in volume) were 3.5% and 2.2% for sugar maple and red oak, respectively. For the small-diameter logs sawn in this study, the percentage-based change in lumber value after drying was 5.9% and 4.6% for red oak and sugar maple, respectively (Table 4). The difference in value loss between these two studies was attributed to the drying approaches used (air *versus* kiln) and the lower final moisture content achieved in kiln drying.

Lumber volume and value recovery models

The ANOVA results based on general linear modeling for the black cherry and sugar maple analyses and Welch's ANOVA for red oak analyses indicated that the variations in LRF were explained, in part, by log grade and/or log small-end diameter (SED). For black cherry, log grade class was found to be significant (Table 5, $\alpha = 0.05$). For red oak, SED class was significant. For sugar maple, the interaction effect between log grade and SED was significant (Table 5). However, for each of these models, the proportion of the total variability of LRF explained by the model was less than 15%. Notably, for red oak, the Tukey post-hoc test results indicated the smaller log diameter class (SED < 10 in) yielded a higher average LRF value than the larger SED class.

The green value per ft^3 of log volume models for black cherry and sugar maple were significant, but for red oak the variance in green value did not appear to be influenced by the SED (Table 5). Similar to the LRF results, the log grade class was significant for black cherry. The log grade class also was a significant factor in the sugar maple model, as was the SED class (Table 5). No interaction effects were significant in the green value analysis.

Table 5. Analysis of Variance Results for LRF and Green Lumber Value Recovered per ft^3 Log with Species, Log Grade Class, and Small-End Diameter Class (SED) included as Explanatory Variables

Species	LRF				Green value ($) per ft^3			
	Model p-value / R^2	Effect [A]	Sig ? / p-value	Tukey groups / mean	Model p-value / R^2	Effect [A]	Sig ? / p-value	Tukey groups / mean
Black cherry	< .0001 / .131	Log grade	Y / < .0001	(**A**) F2&3 6.29 (**B**) F4 5.17	.0015 / .086	Log Grade	Y / .0002	(**A**) F2&3 2.52 (**B**) F4 1.81
		SED	N			SED	N	
		Log grade x SED	N			Log Grade x SED	N	
Red oak	.0105 / .099	Log grade	N/A		N.S.	Log Grade	N/A	
		SED	Y / .0105	(**A**) < 10 7.96 (**B**) ≥ 10 7.10		SED	N	
		Log grade x SED	N/A			Log Grade x SED	N/A	
Sugar maple	.0045 / .096	Log grade	N/A[C]		< .0001 / 0.249	Log Grade	Y / .0003	(**A**) F2&3 2.95 (**B**) F4 2.14
		SED	N/A[C]			SED	Y / .0002	(**B**) < 10 2.09 (**A**) ≥ 10 2.78
		Log grade x SED	Y / .0498	(**A,B**) F2&3 / < 10in [B] (**A,B**) F2&3 / ≥ 10in [B] (**B,C**) F4 / ≥ 10 in [B] (**C**) F4 / < 10 in [B]		Log Grade x SED	N	

[A] Log grade class (2 levels: F2&3, F4); SED = SED class (2 levels: < 10 inch, ≥ 10 inch);
[B] Respective means (top to bottom) for these four interaction groups: 6.92, 6.57, 5.75, 6.29.
[C] As the interaction effect is significant in this model, the main effects log grade and SED are not included.

The dry value per ft^3 of log volume was significant for black cherry and sugar maple, but not for red oak. The same two main effects, log grade class and SED class, were tested for their influence on the dry lumber value recovered per unit of log input. For black cherry, only the log grade class was significant in the model for dry lumber value, with the F2&F3 log grade class yielding higher value per ft^3 of log input than the F4 class. This model explained less than 10% of the variation in the dry value for black cherry. For sugar maple, both the log grade and SED class were significant, but the interaction effect was not. The model for sugar maple dry value recovery explained 25.6% of the variability in the dry value (Table 6).

As discovered by Scholl *et al.* (2008) for black cherry, different dry kiln schedules improved the drying outcomes. A modified kiln schedule used for drying lumber from small-diameter black cherry logs led to fewer drying related defects and less degradation after drying when compared to the conventional dry kiln schedule. Differences in the lumber drying protocols that were applied to the lumber in this study will be further examined to determine if dry-kiln schedule modifications can improve grade and value outcomes for the lumber sawn from small-diameter black cherry, red oak, and sugar maple logs.

Table 6. Analysis of Variance Results for Dry Lumber Value Recovered per ft^3 Log with Species, Grade Class (GR), and Small-End Diameter Class (SED) included as Explanatory Variable

	Dry value ($) per ft^3			
Species	Model p-value / R^2	Effect[A]	Sig? / p-value	Tukey groups / mean
Black cherry	< .0014 / .095	Log Grade	Y / < .0001	(**A**) F2&3 2.34 (**B**) F4 1.68
		SED	N	
		Log Grade x SED	N	
Red oak	N.S.[C]	Log Grade	N/A	
		SED	N	
		GR x SED	N/A	
Sugar maple	< .0001 / 0.220	Log Grade	Y / < .0001	(**A**) F2&F3 2.78 (**B**) F4 2.08
		SED	Y / .0009	(**B**) < 10 1.97 (**A**) ≥ 10 2.73
		Log Grade x SED	N	

CONCLUSIONS

1. The overrun results (based on International ¼-in log rule) from several small-diameter log sawing studies were quite varied. The sample size in this study was larger than in prior studies, which have generally been quite small.

2. Because the Hanks *et al.* (1980) sample sizes in the 8- and 9-inch SED classes were small, the results from this study should be merged with the Hanks *et al.* (1980) results for black cherry, red oak, and sugar maple to make the percentages in that widely used reference document more robust.
3. While the sample sizes in this study were large compared to prior sawmill studies of small-diameter hardwood logs, the sample was a convenience sample obtained from a limited geographic area. Thus, the study and results should be regarded as an extensive case study.
4. Smaller diameter logs with SEDs less than 10 inch produced lumber volume recoveries (as measured by LRF) that were comparable to or greater than those of somewhat larger logs (10- to 13-in SED).
5. Boards with 4/4-inch thickness recovered from small diameter hardwood logs of three important commercial species can be expected to be at least 50% low-grade lumber (No. 3A or 3B Common or below) when logs are sawn. This was true for lumber grade proportions tabulated both before and after the lumber was dried.
6. Approximately 25% of the boards sawn from small-diameter black cherry, red oak, and sugar maple logs dropped in grade when kiln-dried.
7. Sugar maple lumber value recovery, both for green lumber and kiln-dried lumber, was lower for logs with SEDs less than 10 inch than for logs with SEDs of 10 to 13 inch. For black cherry and red oak, SED-based lumber value differences were not detected.
8. Although the volume and value of the lumber sawn from hardwood logs with SEDs smaller than 10 inch were not markedly lower than the volume and value recovered from slightly larger logs, the high percentage of low grade boards that these logs produced is a problem. When grade yields are considered along with handling/processing costs, which is higher per unit of volume for small logs, conventional sawing and drying of red oak, black cherry, and sugar maple small-diameter logs is not likely to be economical in most situations.

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