Innovation Research

Current Status of the US Hardwood Sawmills to Produce Structural Grade Hardwood Lumber

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Hardwood lumber is viable for use in Cross-laminated timber (CLT) manufacturing for structural applications if the lumber were produced to meet the minimum raw material requirements. However, hardwood sawmills do not currently produce lumber that satisfies CLT requirements, so it is necessary to determine if they have the ability and capacity to produce such lumber. The objective of this study was to measure the current capability of sawmills to produce structural grade hardwood lumber and, if not, what changes they must make to be able to do so. A survey of hardwood sawmills in the United States was used to collect sawmill data. The survey was delivered to each sawmill by paper mail and the internet where possible. A total of 2040 sawmills were contacted, and 6.4% of responses were collected. The results indicate that about 10% of the responding sawmills could produce structural grade lumber without additional investment in necessary resources that assume softwood lumber graders can grade hardwood lumber for structural use. Those sawmills that are not ready to begin producing structural grade hardwood lumber need additional resources, such as a four-side planer, a certified lumber grader, and adequate kiln capacity. Cross-laminated timber manufacturers and hardwood sawmills will enter this potential new market because there is a need for expanded lumber markets for sawmills and additional raw material choices for CLT manufacturers.

Keywords: *Hardwood Sawmills; Strucutral Timber, Hardwood Lumber, United States, Cross Laminated Timber*

The Cross Laminated Timber (CLT) industry is exponentially growing market in the US, providing a new market opportunity for oversupplied and low-value hardwood (Grasser, 2015; Quesada, 2018). Two US-based CLT manufacturers have used hardwood lumber available on the market to produce hardwood CLTs (Adhikari et al., 2020). Both manufacturers were optimistic regarding the performance of hardwood lumber for CLTs. The quality of the lumber available in the open market is the major limiting factor in using hardwood. Variations in the dimensions and moisture content of lumber available on the market are the two major limitations reported by CLT industries (Adhikari et al., 2020). Various thicknesses, widths, and random lengths of the lumber increased the material handling and lamella preparation cost. Most of the lumber received by both CLT mills needed additional drying, as none of the lumber was dried to meet CLT lamella's minimum requirement of 12±3% moisture content. Based on CLT mills' experiences, remanufacturing of lumber increased the production time and overall mills expenses. Thus, using appearance grade hardwood lumber from the open market significantly reduced production efficiency and made hardwood CLT less competitive (Adhikari et al., 2020).

The Beck-Group (2018) estimated that CLT demand in the US would be 515,400 m3 by 2025, which would require approximately 3.9 billion bf of nominal lumber. The current production of structural grade lumber (SGL) is limited to softwood species. It is only sufficient to meet 65% of US domestic demands (Howard et al., 2018). Thus, CLT manufacturers must find alternative sources to meet the increasing demand for SGL.

The authors suggest that the production of structural grade lumber from hardwood species can be a viable opportunity to expand the hardwood lumber market. The inclusion of hardwood species in CLT manufacturing offers an additional variation on the product. It potentially adds higher strength performance depending upon species and lumber grade choice. One of the significant reasons to use hardwood lumber in CLT production is to increase domestic hardwood consumption in the US, take advantage of local and regional timber supplies, and expand the hardwood lumber market. At present, hardwood lumber production exceeds the domestic demand. More than 10% of the lumber produced from sawmills is available for the additional market for domestic consumption (Adhikari, 2020).

CLT industries consume a huge volume of lumber, so a very small share of this market has a greater impact on the hardwood lumber business. It is imperative to consider the production of structural grade hardwood lumber (SGHL) for CLT use. If sawmills choose to produce this lumber, there is limited or no market for other structural use. In the past, sawmills were used to produce structural grade hardwood lumber, which was used in structural applications. However, after 1990, the appearance grade market grew more effectively and economically than the structural market (Green, 2005). After then sawmills excluded hardwood species for the structural market. As the consumption of hardwood lumber is limited only for appearance grade after the great recession of 2008-2009, many sawmills moved offshore or closed due to lack of business. It has reduced the use of hardwood species, adding various trouble in forest management. Around 54% of hardwood lumber is manufactured as industrial-grade lumber. This grade of lumber is experiencing direct competition from softwood and plastic pallet raw materials and gradually losing the market share

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(Buehlmann et al., 2017). Alternative markets for industrial-grade lumber would be the best opportunity for lumber producers. Low-grade hardwood lumber would be well suited as CLT raw material (Grasser, 2015; Quesada, 2018; Adhikari, 2020). With this new market, lower-grade lumber can generate more revenues for sawmills, helping to remain in business with sustainable market opportunities. Thus, the production of SGHL for the CLT use provides an additional market to existing sawmills, so it is necessary to examine the status of the sawmills to find their ability to produce SGHL to enter the business.

A CLT mill survey indicated that to begin producing hardwood CLTs for structural application, SGHL must be available commercially to match the quantity and quality (Adhikari et al., 2020). SGHL can be manufactured from low-grade lumber that has a limited market in the current marketplace. Using low-value lumber in CLTs would require additional value-added work because most of the low-value lumber is not dried and surfaced. The potential opportunity for producing structural grade hardwood lumber from lower grade hardwood logs could compete with commercially available dimensional lumber (Adhikari, 2020). As a result, most hardwood sawmills, struggling to generate profit and have an increasing volume of low-value lumber, could find a new market. This unique market opportunity for low-value hardwood lumber would allow the use of a large percentage of timber in national forests not being harvested due to a lack of viable markets (Cumbo et al., 2003).

Two Companies had already used hardwood lumber to manufacture CLTs for non-structural applications such as road mats and crane mats (Adhikari et al., 2020). CLTs for non-structural applications are not required to meet PRG 320 specifications. Thus, manufacturers can use lumber commonly found on the market to meet customer demand. However, hardwood lumber to manufacture CLTs for structural application must meet the requirements of the PRG 320 standard (Grasser, 2015, Adhikari, 2020). The primary and sustainable market for the SGHL will be CLT industries, as structural grade hardwood lumber is not commonly used for other structural applications. So, it is necessary to produce SGHL to establish the market, and it may need multiple adjustments in sawmill operations.

Hardwood sawmills must see the new market for SGHL production as an economically and technically feasible process and a sustainable opportunity. Cross-laminated timbers made from higher-grade hardwood lumber would be costlier than softwood lumber; however, lower-grade hardwood lumber can be economically competitive with softwood CLTs (Brandner, 2013; Beagley et al., 2014; Grasser, 2015). Thus, it is essential to observe the expectation of the sawmills to manufacture new products by switching the products from the old market. Suppose new markets for lower grade hardwood lumber are established. In that case, this will benefit manufacturers and timber owners. However, this new market must justify the economic and operational changes required to produce SGHL.

United States is the major hardwood lumber producer in the world. Since no hardwood sawmills in the United States currently produce the SGHL, it is unknown if any have the capacity and resources to produce SGHL commercially. Understanding the limiting factors to promote the SGHL production on a commercial scale is also not known. Thus, the objective of this study was to understand current sawmill production ability, limitations, and the requirements to produce SGHL from hardwood logs.

Methodolgy

Survey

A survey method was chosen as the best way to capture data from sawmills and to measure the current capacity, limitations, and production status of hardwood sawmills. A survey was chosen because it is a powerful instrument to study a large population (Allen et al., 2011) with higher variability, like hardwood industries. An anonymously conducted survey provides authentic and explicit replies from the participants (Groves et al., 2009). Additionally, most industries are sensitive to their personal information, so the anonymous survey can be an opportunity to obtain fact-based data (Dillman et al., 2009).

According to Howard and Liang (2016), over 98% of hardwood sawmills were in the US south, east, and northern regions. Thus, the survey was limited to hardwood lumber producers from these regions. A list of sawmills was obtained from the "The Forest Products Network" database and the database service company "SicCode." Both databases were merged, and all duplicates were removed. A total of 2040 industries were identified as hardwood lumber producing and processing sawmills, the total number of the samples for this survey.

The survey was designed to measure the current ability of hardwood sawmills to produce SGHL under the framework described by Groves et al. (2009) by following all four steps for surveys designed. The survey aimed to measure the current capability of sawmills based on existing technology, awareness of sawmills, grading capability, production strategies of the sawmills, and requirements of various resources, and possible collaboration with other stakeholders. The survey's design and implementation met the Tailored Design Method (TDM) to obtain the best response rate.

The surveys were developed to measure the current capacity and practices of the sawmills, awareness of structural grading of hardwood, expected demands for new products, estimated lumber value for the SGHL, production strategies of the sawmills, current technology, supply chain practices, market and marketing issues, collaboration opportunities, and investment opportunities. The first section of the survey collected general information on sawmills, such as species sawn at the sawmills, annual production volume, percentage of lower grade lumber using current sawing practices, and average production cost. The second section collected information on the sawmills' status, expectations, and opportunities to produce and market SGHL. The third section focused on the need for technology and resources for the sawmills to produce SGHL. The answers to the third section were dependent on the answers from the other two sections since they measured the additional need for resources for the sawmills to begin the production of SGHL. The survey was reviewed and approved by the Internal Review Bureau (IRB) of Virginia Tech before being dispatched to sawmills.

Procedure

The survey was conducted using two methods: paper mail and the internet. The paper mail survey was sent to 2040 sawmills. The internet survey was designed and delivered to 485 sawmills with email contact available in the database through Qualtrics. Thus, 485 sawmills were contacted through both paper and an internet survey. On both the paper and the internet survey, sawmills were first informed and asked to choose only one mode to avoid duplicate responses from the same sawmills. For the mixed mode of data collection, response collection was observed for the bias based on the delivery model. In this case, a paper survey and Qualtrics were a visual mode of data collection, producing a similar response (de Leeuw et al., 2018). Thus, both methods' response was combined and used as a response collected from the unimode data collection method for the analysis (de Leeuw et al., 2018). The second wave of surveys was sent 35 days after the first survey, eliminating the companies' names that had responded to the first wave. The second wave of internet surveys was also sent on the same date as the hard copies. A final reminder was sent to all sawmills 30 days after the second wave of distribution to request that they complete the survey soon. The online survey was closed 95 days after initiation.

All the survey responses were individually recorded for each sawmill. Each sawmill was assigned a number based on the receiving date to identify and verify the sawmill, if necessary. The response obtained from the internet survey was stored in a Qualtrics database until the survey was closed. The final survey response from Qualtrics was downloaded in spreadsheet format and merged with the paper survey responses. Both sources were marked and recorded for further analysis. Contingency analysis of the paper and internet wave was observed to identify any sampling differences based on the mode of delivery.

Design and Analysis

JMP statistical software (JMP, 2020) was used to summarize and analyze the survey response. While using different statistical methods to evaluate the response alpha (α) value of 0.05 was used. Before analyzing the responses, each question was coded based on the response from the sawmills. Two different datasheets were prepared to analyze the survey responses. The first datasheet included the actual responses from the sawmills used for the categorical analysis of the data. The second sheet was modeled to observe the distribution of the response of the sawmills across various categorical variables. The reliability test of the surveys was conducted based on sawmills' responses. A nonresponse bias test of the survey was analyzed to synthesize the response for legitimate conclusions.

Results and Discussion

Survey Response, Reliability Test, and Nonresponse Bias Test

There was a different response rate for the internet and paper surveys. Only 19% of the paper surveys and 24% of the internet survey were returned by sawmills. Most of them were unaware of lumber requirements for CLT, which was identified as the primary cause for a minimum response rate. Producing lumber for CLT use is new for the sawmills. Many sawmills did not or respond partially to the second and third sections of the surveys were excluded for further analysis. Only 82 of the returned responses from the paper survey were complete enough to be used for further analysis, accounting for 4% of the total surveys sent to sawmills. From the Qualtrics survey, out of 485 surveys, only 42 were complete and used in further analysis. When the responses from sawmills were sorted, it was found that only one sawmill responded on both paper and the internet survey. The internet survey response for this sawmill was used in the final tally, and the paper survey was excluded.

The internet and paper surveys across sawmill types (based on sawing hardwood only or both) were evaluated to understand the sample pool. The results from the Chi-square statistics test indicated that the sawmills were representative of the same sample pool, χ^2 (1, N = 124) = 1.219, p = 0.27, so surveys from both instruments could be combined for further analysis. The combined response of the survey was 124, which was approximately 6% of the data pool. As the adjusted sample pool was 1938, after removing all non-delivered mail, the response rate of useful data increased to 6.4%. Thus, full caution is required in generalizing the results due to the low response rate compared to the sample pool size. Details of the survey dispatch and collection are explained in Table 1.

The reliability of this survey was measured based on Cronbach's α score of the questionnaires. The score observed was higher than the cutoff score of 0.7, which helps conclude that the data collection instrument for this research is valid and reliable. The difference between the survey non-respondents and respondents was measured with a nonresponse bias test (Lambert et al., 1990). The respondents were classified into two groups corresponding to the response time to measure the nonresponse bias test. The response obtained from the first

Table 1: Information on Survey Sample Pool and Sawmill Responses

Particular	Counts	Particular	Counts
Total survey sent by mail	2040	Total survey sent by Qualtrics	485
Total returned by mail	384	Total response from Qualtrics	118
Total completed responses from mail	82	Total returned as nondelivered from Qualtrics	93
Total returned as nondelivered	103	Total completed response from Qualtrics	42
Total useful responses	124		
Useful response percentage		6.4%	

distribution of the mail survey was categorized as "Wave 1," and the response collected after distributing the second set of surveys and a reminder postcard was recorded as "Wave 2." The Chi-square statistics test of the sawmill's types vs. the waves helped to conclude that the sawmills from Wave 1 and Wave 2 were from the same sample pool, $\chi 2$ (1, N = 124) = 3.218, p = 0.073. So, all sawmills who chose not to respond were represented by those who responded to the survey.

Demographics of participants

Sawmills responses were sorted into four demographic categories: sawmill type, annual production capacity, available 2 common and lower grade lumber volumes, and production cost. The several categorical responses used in data collection were reduced to a few categories for efficiently and effectively analyzing the response data. The details of reduced categories are presented in Table 2, and the distributions of the various categories are summarized in Figure 1.

Under reduced categories, 56% of the sawmills were of small size and had an annual production capacity of less than 10 MMBF. Another 31% of the sawmills are medium-sized and produce up to 25 MMBF of lumber annually. Approximately 69% of the sawmills that participated are producing only hardwood lumber. Also, 46 % of the sawmills have average and another 40% yield minimum volumes of two common and lower grade lumber annually. . A very important finding was observed on production cost. Only 15% of sawmills have a higher production cost of more than \$350 to produce 1000 bf of lumber. About 49% of the sawmills reported competitive costs of below \$250 to produce 1000 bf of lumber annually.

The survey response to measure sawmills' current capacity, expectation, willingness, and requirements to produce SGHL from low-value hardwood logs was recorded using four levels: sawmill types, sawmill size, lower-grade lumber percentage, and production cost. The Chi-square statistics test of the sawmills participating in the survey showed no statistical differences in the distribution of sawmills based on sawmill size; $\chi 2$ (1, N = 124) = 0.076, p = 0.963; the volume percentage of lower grade lumber $\chi 2$ (1, N = 124) = 5.758, p = 0.056; and production cost, $\chi 2$ (1, N = 124) = 1.845, p = 0.40 across sawmill types. So, the survey response was discussed and presented under one categorical factor: sawmill types for further analysis.

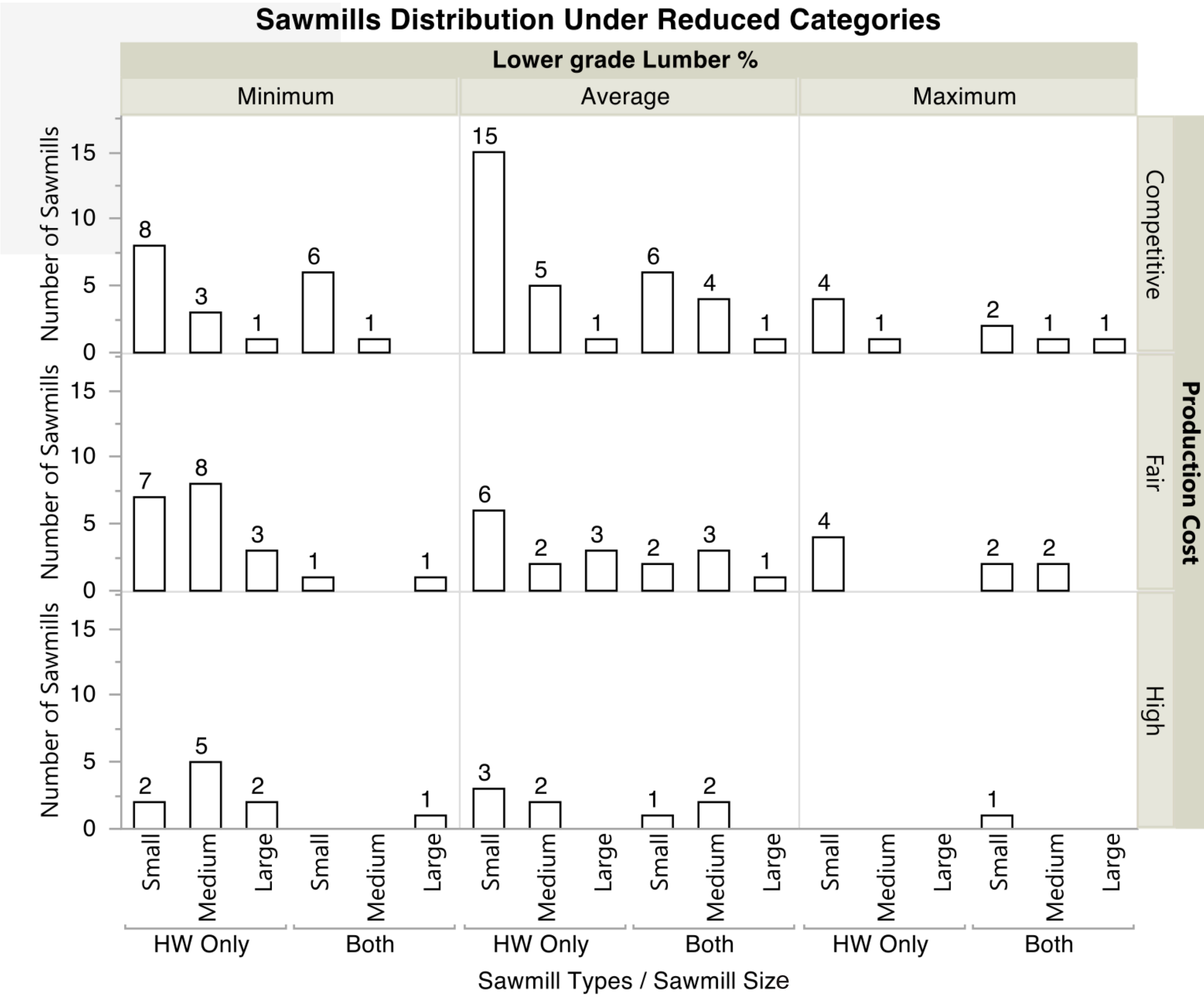

Figure 1. Distribution of the Various Categorical Factors from Data Collection Under reduced categories

Table 2. Reduced Demographic Categories for Survey A

Reduced categories for sawmill Types			**Reduced categories for 2 Com and lower grade lumber volumes**	
HW only	saw 100% HW species		Low	Less than 40%
Both	saw < 100% HW species		Average	41%- 60%
			High	More than 60%
Reduced categories for sawmills size			**Reduced categories for an average production cost of 1000BF lumber**	
Large	More than 25 MMBF		Competitive	Less than $250
Medium	10 to 25 MMBF		Fair	$251-$350
Small	Below 10 MMBF		High	More than $350

Survey Responses

The survey was designed to know the tree species sawn at sawmills to determine the commercial availability of suitable species for CLT use. Out of 124 sawmills, 121 responded with the percentage of hardwood lumber produced in 2018 by species. The significant species sawn was red oak, which accounted for approximately 30% on average, ranging from zero to 80% of the total lumber production for a particular sawmill. The second and third species sawn in participating sawmills were yellow poplar and white oak, which had a mean of approximately 15% for both. Hard maple and soft maple were the other dominant hardwood species sawn in the participating sawmills, accounting for an average of 9% and 8% by volume of the total lumber produced in 2018. A comparison of various species and distribution of each species across various sawmills is presented in Figure 2.

This study found that approximately 85% of the hardwood

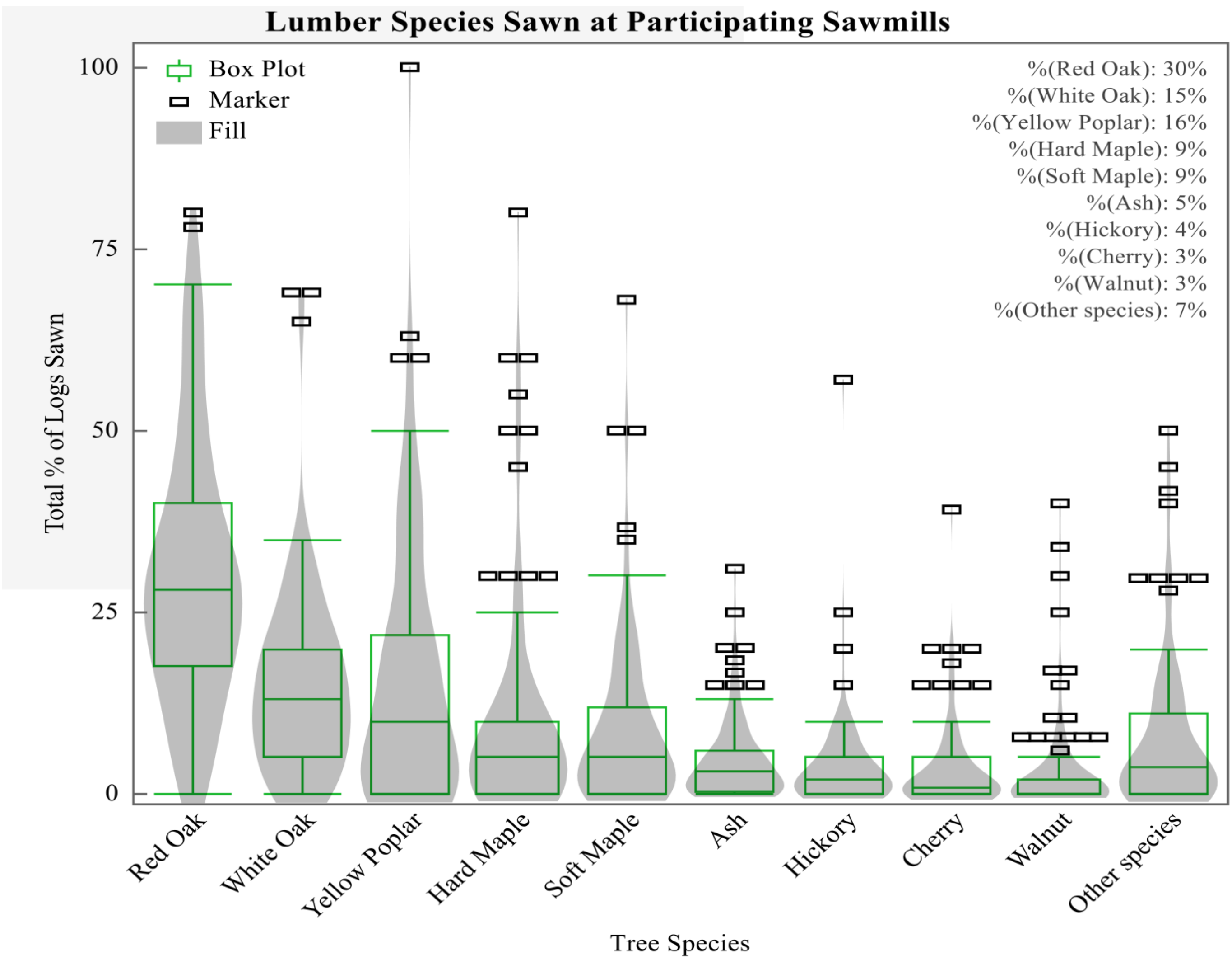

Figure 2. Volume Percentage and Distribution of Lumber Species Sawn at Participating Sawmills

lumber produced in 2018 was from species studied to evaluate the potential to manufacture structural grade CLTs in the US and Europe. Adhikari et al. (2020) reported that species used to manufacture CLTs by US-based CLT industries were red oak, white oak, ash, beech, and soft maple. Since 2013, the American Hardwood Export Council (AHEC) has worked with different companies in Europe to manufacture yellow poplar CLTs (AHEC, 2019). AAs reported in the USDA Wood Handbook by R. J. Ross (2010), yellow poplar and soft maple bond better than other hardwood species and species like ash, beech, red oak, and white oak bond satisfactorily. Yellow poplar and soft maple, which account for 24% of the total lumber produced in 2018, bond well and have specific gravity close to other softwood species commonly produced for the structural market. These species have the potential to begin the production of SGHL commercially.

Sawmills' current capacity was measured on the ability to saw SGHL from logs or cants and surfaced and dried them to match CLT raw material requirements based on the existing technology of sawmills. More than 88% of the sawmills responded that they could rip SGHL from whole logs, and 97% could also rip SGHL from cants. Only 23% of the sawmills had the technology to surface four sides of the lumber. Around 50% of the sawmills had enough kiln capacity, whereas 27% also had excess.

Sawmills' awareness of SGHL was another factor surveyed, and more than 85% of the sawmills were aware of SGHL. However, only 50% knew about SGHL grading rules for structural applications. One important finding is that 37% of the sawmills employed a grader who could grade both NHLA and structural grade lumber based on softwood species rules. These graders can be trained and certified to grade SGHL. Sawmills were also asked for their willingness to collaborate with other stakeholders to produce SGHL. More than 76% of the sawmills would collaborate with other sawmills to produce and meet the SGHL demand, and 79% of sawmills would collaborate with other stakeholders like brokers, distributors, concentration yards, or others to meet the lumber demand. However, only 56% of the sawmills would employ shared SGHL graders. We found that 73% of the sawmills would share production information with CLT industries, and 70% would share investments with CLT industries to produce SGHL if there was an opportunity.

For commercial production of SGHL, approximately 31% of the participating sawmills required a return of more than 10% compared to NHLA lumber to produce SGHL. However, 24% of the sawmills were ready to produce SGHL at equal lumber value based on NHLA grade. Fifteen percent of the sawmills required 1-5% higher lumber value to produce SGHL, and another 26% required 5-10% additional lumber value. The past study suggests that the production of SGHL from whole logs is less effective and provides less return to sawmills (Green, 2005). Mixed grade lumber production of SGHL and NHLA grade can be advantageous (Allison et al. 1987) to sawmills, so sawmills were asked when they choose to produce SGHL over NHLA grade lumber as product mix. Based on lumber value, 54% of the sawmills would consider producing SGHL as a mixed product with NHLA grade lumber if the return were below 5% but higher than NHLA grade lumber. In contrast, 74% of sawmills would consider producing SGHL as a mixed product if the return were higher than 5% of NHLA grade lumber value.

Another critical factor is the capacity of the sawmills to produce SGHL to meet the higher annual demand with mixed grade lumber

Table 3. Response to Sawmills' Production Requirements for SGHL and Planned Strategies to Produce as Product Mix

Categories / Questions	Responses	Both HW and SW Lumber Producer	HW only Lumber Producer
Annual Demand (AD)	Up to 1 MMBF	8%	5%
	Up to 3 MMBF	18%	27%
	Up to 5 MMBF	24%	22%
	More than 5 MMBF	50%	46%
Required Lumber Value (RLV)	Equal	20%	35%
	1- 5%	21%	13%
	5-10%	33%	22%
	More than 10%	26%	30%
Production strategies for equal and up to 1-5% higher lumber value (PSEB5) than NHLA grade lumber as product mix	No	42%	40%
	Yes	58%	60%
Production strategies for 5% and higher lumber value (PSA5) than NHLA grade lumber as product mix	No	22%	25%
	Yes	78%	75%
Total Responses	N=124	39	85

Table 4. Response on Sawmills Status to Produce SGHL by Various Levels

Categories	Questions	Responses	Both HW and SW Lumber Produce	HW only Lumber Producer
Current capacity-CC	SGHL Sawing Capacity	No	10%	13%
		Yes	90%	88%
	Can saw cants for SGHL	No	2%	3%
		Yes	98%	97%
	S4S Capacity	No	67%	74%
		Yes	33%	26%
	Have enough kiln	No	26%	44%
		Yes	74%	56%
	Have excess kiln	No	66%	68%
		Yes	35%	32%
	Graders can grade SGHL	No	60%	59%
		Yes	40%	41%
Awareness -AW	Aware of SGHL	No	13%	14%
		Yes	87%	86%
	Aware of SGHL grading rule	No	43%	52%
		Yes	57%	48%
Collaboration Opportunity -CO	Collaboration with other SM	No	27%	17%
		Yes	73%	83%
	Ready to share grader	No	40%	45%
		Yes	60%	55%
	Can share production information	No	38%	18%
		Yes	62%	82%
	Collaborate with the third party	No	17%	14%
		Yes	83%	86%
	Accept investment in collaboration	No	20%	23%
		Yes	80%	77%
Required Resources -RR	Equipment	No	70%	61%
		Yes	30%	39%
	Certified Grader	No	41%	35%
		Yes	59%	65%
	4-side planner	No	29%	17%
		Yes	71%	83%
	Sorting capacity	No	49%	50%
		Yes	51%	50%
	Kiln capacity	No	48%	42%
		Yes	52%	58%
	Lumber storage	No	56%	45%
		Yes	44%	55%
	Total response	N=124	39	85

production and the associated cost. Suppose the production cost of the SGHL is higher than NHLA grade lumber, and sawmills also need 5-10% higher returns from the new product. In that case, it is essential to determine the economics of the new product and ascertain the feasibility of producing SGHL by individual sawmills. SGHL will not be the primary choice for CLT industries if the cost is significantly higher than current softwood lumber unless hardwood provides an additional economic benefit over commercially available structural grade lumber. Thus, the first step in the commercial production of SGHL is to develop a method to saw logs that can convert lower-grade lumber into SGHL and to determine the potential volume of SGHL for the commercial market.

CLT is still a relatively new material for the construction industry in the United States, and raw materials for a new market are challenging. Structural grade hardwood lumber is not produced by hardwood sawmills yet. Sawmills must develop new strategies for the required changes to produce SGHL. Also, to implement new strategies, sawmills need to guarantee a market and returns from SGHL production. Thus, sawmills were asked to provide their required annual lumber demand, value to begin SGHL production, and corresponding production strategies. The response of the sawmills, based on sawmill types, is tabulated in Table 3. Around 43% responded that they would begin SGHL production if they saw an annual demand of more than 5 MMBF. Another 19% and 26% would produce SGHL if the demand were up to 5 MMBF and 3MMBF, respectively. The other 4% would produce SGHL with an annual demand of up to 1 MMBF.

It was expected that sawmills might require new or additional resources to begin production of SGHL. So, each sawmill was asked what types of resources they might need to acquire or upgrade to produce the SGHL. In response to the need for individual resource types, 63% of the sawmills reported having sufficient sawing technology to produce SGHL. At least 53% of the total participating sawmills required an upgrade in sorting capacity for additional lumber types, 57% required investments in acquiring or improving the kiln capacity. About 51% required investing in new storage capacity for SGHL lumber. The most required investment would be on a four-side planer. More than 75% of the participating sawmills need this technology. Sawmills would need to hire a certified grader to grade SGHL, and 66% of them required investing in hiring certified graders to grade SGHL for the commercial market. The details of the survey response on capacity and requirements based on sawmill types are presented in Table 4.

If we agree with the sawmills with their assumption that softwood lumber graders also can grade SGHL, commercial production of SGHL required additional investment for more than 90% of the sawmills that participated in this survey. The most frequently required resource to produce SGHL is the four-side planer, as 75% of all sawmills that participated did not have one. However, these sawmills could work together with milling industries to surface SGHL. The second most needed resource was certified graders to grade SGHL. At least 70% of responding sawmills needed to invest in a certification to produce SGHL commercially. Sawmills must invest in training and certification of graders to produce SGHL.

Conclusion

The objective of this study was to measure the current capability of sawmills to produce structural grade hardwood lumber and, if not, what changes they must make to be able to do so. The observed results from this survey on the current capacity and resources required by sawmills help to conclude that around 10% of the participating sawmills were ready to produce SGHL without additional investments provided available SGL graders can grade SGHL.

The primary driver for sawmills to initiate SGHL production was identified as a stable market with significant demand and economic advantages over NHLA grade lumber. More than 60% of sawmills would choose to produce SGHL as a product mix if the value of SGHL was 5% or higher compared to NHLA lumber. Additionally, more than 50% of the sawmills would need the annual demand of SGHL to be greater than 5 MMBF to begin production. More than 90% of the participating sawmills must invest in additional resources to produce SGHL and need further information to ensure that the potential return for SGHL production is sufficient to cover the required expenses and add minimum benefits to sawmills.

The researchers predicted that there would be a market for SGHL as a raw material for CLT manufacture and that market demand for these CLTs would expand. Currently, none of the CLT companies are near a pocket region of hardwood. Thus, market access to SGHL is exceptionally complicated, with many obstacles to overcome to compete with existing raw materials. If the CLT manufacturers in Maine (proposed plant) and Alabama were to introduce SGHL in CLTs, the hardwood sawmills across the southeastern and northern regions could find access to a new market and ultimately help expand the hardwood lumber market. However, the potential of SGHL can only be explored if CLT manufacturers are interested in using it on a commercial scale and collaborate with the hardwood sawmills to prepare the lumber based on their needs. Thus, successfully implementing SGHL on a commercial scale requires an aggregated plan to produce lumber which requires a stable market with continuous demand and higher return compared to NHLA grade lumber to benefit sawmills.

An important next step for commercial production of SGHL would be to identify sawmills across the region that could produce SGHL with minimal investment. As the sawmills' responses were measured on a nominal scale, the need for the sawmill's resources cannot be quantified, making it difficult to estimate the potential cost of the investments. Still, if the sawmills must invest in high-cost resources, it is more challenging for them to produce SGHL. Those sawmills that must invest in up to two resources to produce SGHL could see the opportunity to produce SGHL with minimum investment, accounting for more than 32% of the sawmills that participated in this survey. These sawmills could work in collaboration with CLT manufacturers to develop a working protocol to produce SGHL. This protocol must define the minimum quality of SGHL acceptable for CLT use. Sawmills ready to produce SGHL based on their current technology must train their graders to grade SGHL and get certification to produce SGHL. As each step is completed and both sawmills and CLT manufacturers are confident about SGHL quality and quantity, it can be produced commercially.

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