Effects of Seasonal Timber Harvesting Restrictions on Procurement Practices

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Abstract

Wisconsin's forest products industry relies on a consistent supply of sustainably produced timber for its mills; however, recent research suggests significant seasonal variation in timber sale availability. We conducted a survey of Wisconsin mills to examine their procurement practices and assess how seasonal timber harvesting restrictions (STHRs) affect the forest products industry. Fifty-seven mills responded to the survey, which represented a 40 percent response rate. Respondents processed approximately 75 percent of the state's annual roundwood production. The average procurement radius ranged from 75 miles for small sawmills to over 120 miles for pulp mills. Peak inventory levels exceeded 30 days during each quarter for both pulp mills and sawmills, and peak inventory levels during the first quarter exceeded 60 days. Respondents reported that STHRs were common in the state and mills had adjusted their procurement practices in response. Pulp mills estimated that STHRs cost each firm an average of nearly $2.7 million annually, or $4.93 ton^{-1} of wood purchased during the year, whereas small sawmills reported average additional costs of $188,888 per firm ($10.33 ton^{-1}). Seasonal weight limits on public roads, oak wilt restrictions, and access and transportation restrictions on individual timber sales were reported to have the greatest impact on mills. Continued cooperation is needed among foresters, landowners, and the forest industry to apply STHRs in a manner that protects the forest resource while maintaining a consistent and sustainable supply of timber to the forest industry.

Wisconsin is the number one paper-making state in the United States (Wisconsin Department of Natural Resources [WDNR] 2016) and the forest products industry employs over 62,000 people (WDNR 2015b). The forest products industry relies on a sustainable supply of timber from Wisconsin's 17 million acres of forestland to make products desired by the marketplace. Today's timber markets are global in scope, and therefore Wisconsin's mills must produce finished products at a competitive cost regionally and internationally. The cost of wood fiber is the largest component of direct manufacturing costs in the forest products industry (Siry et al. 2006), which means it is essential that Wisconsin mills procure timber at a competitive cost. Recent research found that delivered pulpwood prices in the Lake States were among the highest and most volatile in the United States between the third quarter of 2013 and the second quarter of 2015 (Gibeault et al. 2015).

Despite the importance of timber procurement to the profitability of Wisconsin's forest industry, there is very little information in the published literature regarding timber procurement practices in the state. Stier et al. (1986) found that pulp mills supplied 80 percent of their timber from within 125 miles of the mill, but the long distances were generally because of the need of a few mills to secure supplies of relatively scarce softwood species. Only 5 to 10 percent of mills' timber was purchased directly from landowners, with the vast majority (75%) purchased from independent loggers. Mills built inventories during the winter season in preparation for spring breakup. Timber deliveries were curtailed during spring because of soft ground conditions in the woods and reduced weight limits on many public roads. Inventory levels remained stable during summer and fall, and reached their lowest level in November in preparation for the winter buildup. The average inventory level for firms was 2 to 3 months. Seasonal inventory patterns were similar in the northeastern United States, but northeastern mills generally held less inventory (Todd and Rice 2005).

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There have been many changes in forest ownership and regulations since the analysis of Stier et al. (1986). One change is application of seasonal timber harvesting restrictions (STHRs). Many timber sales are restricted to frozen ground to reduce risk of soil or hydrological damage (e.g., Wausau and Marathon County Parks, Recreation, and Forestry Department 2015). The state of Wisconsin and local municipalities reduce weight limits on public roads at the onset of spring thaw to prevent damage to public roads (Wisconsin Department of Transportation 2016). In addition, the WDNR and Wisconsin Council on Forestry (WCOF; 2016) recommend that stands with at least 15 ft^2 $acre^{-1}$ of oak (*Quercus* spp.) basal area not be harvested between early to mid-April and July 15 to avoid spread of oak wilt (*Ceratocystis fagacearum* Bretz), a fungal disease affecting oak species. Although limiting some stands to winter harvesting is a longstanding practice in Wisconsin, oak wilt restrictions were not recommended until 2007. Because of these restrictions and others, fewer than half of timber sales were available to harvest April to July according to a recent analysis (Demchik et al. 2018). Although some restrictions, such as spring road weight and endangered species regulations, were the result of state or federal regulations, the vast majority of STHRs were motivated by foresters' professional judgment or landowner objectives (Conrad et al. 2017). Finally, because the forest industry divested most of its forestland (Hickman 2007), most mills cannot overcome seasonal raw material shortages with timber from their own land.

STHRs may increase timber procurement costs. Todd and Rice (2005) found that weather and wood availability had a major influence on procurement practices. In Maine, mill inventories peaked in March because of wet weather in spring (Todd and Rice 2005). STHRs affect the supply chain in a similar manner to weather by restricting access to timber, or some species of timber, during part of the year. Therefore, mills would be expected to respond to STHRs in the same way that they respond to weather-related supply limitations. However, high inventory levels force companies to hold capital in an unproductive capacity and requires large storage space, which increases operating costs (Lang and Mendell 2012). On the other hand, maintaining low inventories during periods of constrained harvest activity is not cost effective either because timber prices often increase as supply restrictions approach (Todd and Rice 2005).

STHRs imposed on Wisconsin's wood supply chain have the potential to alter timber procurement practices and increase the cost of delivered wood. Understanding the costs and mills' response to these restrictions is important for policy makers and foresters to consider as they design policies and administer timber sales to protect the forest resource and maintain a vibrant forest products industry. Therefore, the goals of this research were to document Wisconsin mills' procurement practices and analyze their response to and the costs of STHRs.

Methods

A mail survey of Wisconsin mills was conducted to document their procurement practices and analyze how STHRs affect their business. The survey was conducted during late summer and early fall of 2015 using the tailored design method (Dillman 2007). Mills received four contacts: a prenotice letter, a cover letter and questionnaire, a postcard, and nonrespondents received a second cover letter and questionnaire. A list of 165 mills was obtained from US Department of Agriculture Forest Service Forest Inventory and Analysis data, Wisconsin's Wood Using Industry Online database (University of Wisconsin–Madison et al. 2006), and personal contacts with Wisconsin Department of Natural Resources forest products specialists. All primary mills identified from these sources were included in the survey.

The questionnaire consisted of 38 questions that asked about mill characteristics (e.g., type of mill, species purchased), timber procurement practices, and STHRs. Of the 38 questions, 20 were open-ended and generally requested quantitative data, 10 were 5-point Likert scale questions, and 8 were closed-ended. The questionnaire was pretested by procurement foresters before the initial mailing.

Mills were placed into three categories for analysis on the basis of their responses: large sawmills, small sawmills, and pulp mills. Large sawmills purchased at least 50,000 tons of timber per year and produced solid wood products. Small sawmills purchased fewer than 50,000 tons of timber annually and produced solid wood products. Pulp mills included pulp and paper facilities, as well as composite mills and other facilities that purchased small-diameter timber (i.e., $<$8 in. small-end diameter inside bark).

The cost per ton of STHRs was estimated by dividing each mill's reported cost of STHRs by its annual wood consumption. Total STHR cost incurred by pulp mills was estimated by multiplying the average cost per ton reported by responding pulp mills by the annual pulpwood harvest (WDNR 2015a). Total STHR cost to sawmills was estimated by multiplying the average cost per ton reported by sawmills by the annual sawtimber harvest (WDNR 2015a). The total cost of STHRs to the forest industry was estimated by summing the costs to pulp mills and sawmills.

Responses between mill types were compared using the Kruskal-Wallis test and the Dunn-Bonferroni post hoc procedure. The 2-tailed sign test was used to test whether median current inventory levels were different from median inventory levels that mills reported would be necessary absent STHRs. Similarly, on 5-point Likert scale questions, we used a 2-tailed sign test to determine whether the median response was different from neutral ($\tilde{x} = 3$). The sign test was chosen because it is appropriate for any population distribution (Ott and Longnecker 2010). Companies that owned multiple mills but purchased timber as a single entity were counted as a single entity. All statistical tests were conducted at $\alpha = 0.05$ using SPSS (IBM Corp. 2012).

Results

Of the 165 surveys mailed to mills, 23 facilities were removed from the sample because the survey could not be delivered, the facility had closed, or the recipient did not purchase its own timber. Sixty-three questionnaires were returned, of which 57 contained usable data, yielding a response rate of 40 percent. Respondents included 12 large sawmills, 35 small sawmills, and 10 pulp mills. Twenty-nine sawmills utilized hardwoods exclusively, 8 utilized softwoods, and 10 processed both hardwood and softwood species.

Respondents purchased a combined 7.5 million tons of wood annually, representing approximately three-quarters of the growing stock volume harvested annually in Wisconsin (Perry 2015). The high percentage of annual wood consumption accounted for by respondents suggests

that many of the nonrespondents were closed, or were small, hobby-type mills. Because of the large percentage of the processed volume accounted for in our study, nonresponse bias should not be of concern.

Procurement practices

The average timber procurement radius ranged from 75 miles for small sawmills to 124 miles for pulp mills (Table 1). Pulp mills purchased an average of 74 percent of their timber as roundwood, 18 percent as clean chips, and the remainder as whole tree chips. Sawmills purchased an average of 77 percent of timber in lengths shorter than 16 feet, 13 percent between 16 and 32 feet, with the remainder purchased in lengths exceeding 32 feet. All pulp mill roundwood purchases were 100-inch pulp sticks.

Wisconsin mills purchased the majority of their raw material as gatewood from independent loggers (Table 2). Pulp mills purchased approximately 90 percent of their roundwood and chips using this strategy. The largest source of timber for all mill types was family forestland (Fig. 1). Small sawmills and pulp mills were generally more reliant on family forest landowners than large sawmills. County forestland accounted for more than 10 percent of the timber purchased by each mill type, but was a greater share of large sawmills' wood supply compared with other mill types.

Pulp mills generally had the largest procurement staffs, averaging four-and-one-half workers per organization, whereas large sawmills and small sawmills employed two and three procurement foresters, respectively. More than half of responding pulp mills and large sawmills did not have procurement personnel purchasing stumpage directly from landowners. Seventy-three percent of small sawmills employed at least one forester making direct stumpage purchases. Small sawmills and pulp mills made, on average, more than 83 percent of their direct stumpage purchases from family forest landowners. Large sawmills made 27 percent of their direct purchases from counties, 14 percent from federal land, and 13 percent from state land. Pulp mills rated increasing the amount of timber on the market as the most important reason for making direct stumpage purchases, small sawmills rated reducing delivered timber cost as most important, and large sawmills rated greater control over wood supply and overcoming STHRs as most important, although differences in rankings between mill types were not statistically significant ($P > 0.05$).

Peak inventory exceeded 30 days during each quarter for all mill types (Fig. 2). Peak inventories were generally highest during the first quarter, declined in the second quarter, and were lowest during the third and fourth quarters. Respondents suggested that STHRs caused them to hold high inventory levels, particularly during the first and second quarters (Fig. 2). Inventory strategies were highly variable, and therefore the only statistically significant changes in inventory resulting from STHRs were during the first ($P = 0.04$) and second ($P = 0.04$) quarters at pulp mills and during the first quarter at small sawmills ($P = 0.01$) when inventories were higher than would be necessary absent STHRs. Seasonal timber harvest restrictions were the most important factor influencing inventory levels for pulp mills, whereas weather was the most important factor for sawmills of all sizes (Fig. 3). General timber availability, as influenced by STHRs as well as other reasons, and weather were both rated as important factors in determining inventory levels for mills of all types ($\bar{x} \geq 4$).

More than 90 percent of respondents reported an increase in the price they paid for wood over the past decade. Approximately 40 percent of sawmills reported a decline in the quality of wood delivered to their mill over the past decade. Seventy, 65, and 50 percent of large sawmills, small sawmills, and pulp mills, respectively, reported that less timber was available at the time of our survey than was available 10 years before.

Respondents reported that loggers operated at 70 to 80 percent of capacity outside of the spring breakup period. Fifty-two percent of mills suggested that weather was the primary cause of unutilized logging capacity in Wisconsin, whereas 33 percent blamed STHRs. Fewer than 5 percent of respondents suggested that mill quotas were the primary cause of unutilized logging capacity. Fifty-nine percent of respondents stated that loggers were rarely (<4 wk yr^{-1}) placed on restrictive quotas, 31 percent stated that loggers were occasionally (4 to 8 wk yr^{-1}) placed on quota, whereas the remainder reported that loggers were commonly (9 to 26 wk yr^{-1}) placed on quota.

Table 1.—Procurement radius (miles) by mill size and type.[a]

	Avg. procurement radius (mi)	SE	Min.	Max.
Large sawmill (≥50,000 tons)	106	11	40	300
Small sawmill (<50,000 tons)	75	6	10	200
Pulp mill	124	11	75	250

[a] Procurement radius was defined as the distance within which the organization purchased 90 percent of its timber.

Table 2.—Roundwood and chip procurement strategies for large sawmills, small sawmills, and pulp mills in Wisconsin.[a]

Procurement practice	Large sawmill (≥50,000 tons)	Small sawmill (<50,000 tons)	Pulp mill
Gatewood from loggers			
Mean (SE) reported (%)	68.6 (7.1)	59.3 (5.6)	90.0 (2.4)
Total reported volume (tons)	822,250	250,653	5,143,247
% total volume	70.2	51.9	88.3
Gatewood from dealers/brokers			
Mean (SE) reported (%)	13.6 (5.8)	2.2 (1.3)	1.8 (0.9)
Total reported volume	89,875	21,600	160,046
% total volume	7.7	4.5	2.7
Direct stumpage purchases			
Mean (SE) reported (%)	14.1 (4.2)	31.3 (5.3)	2.8 (1.0)
Total reported volume	233,250	186,538	358,000
% total volume	19.9	38.6	6.1
Fee land			
Mean (SE) reported (%)	3.6 (1.9)	4.9 (2.7)	0
Total reported volume	26,000	16,745	0
% total volume	2.2	3.5	0
Other[b]			
Mean (SE) reported (%)	0 (0)	2.4 (1.5)	5.4 (2.3)
Total reported volume	0	7,494	162,680
% total volume	0	1.6	2.8

[a] Percentages may not sum to 100 because of rounding.
[b] Sawmill residuals was a common response in this category for pulp mills.

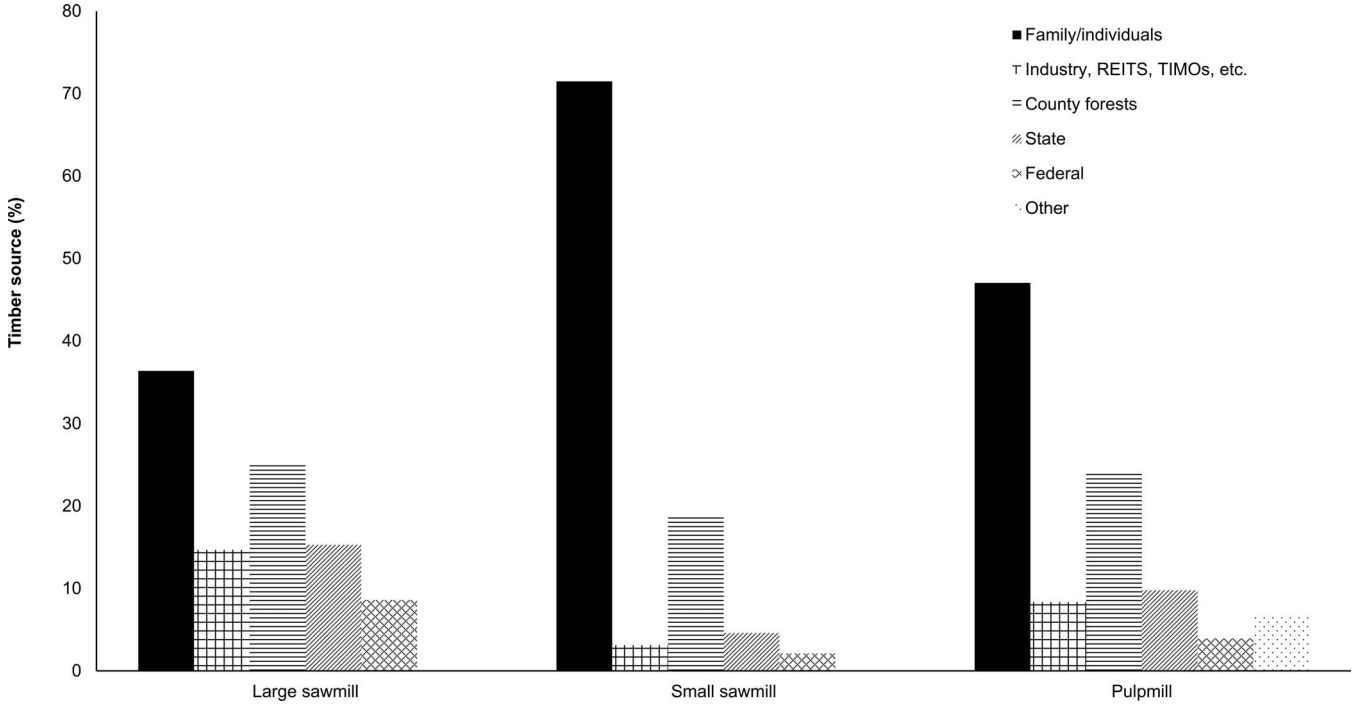

Figure 1.—Timber sources for forest products industry mills in Wisconsin.

Seasonal timber harvesting restrictions

Overall, 70 percent of responding mills had adjusted their procurement practices because of STHRs, including all responding pulp mills, 66 percent of large sawmills, and 63 percent of small sawmills. Fifty-five percent of large sawmills, 53 percent of small sawmills, and 30 percent of pulp mills had altered their species mix because of STHRs.

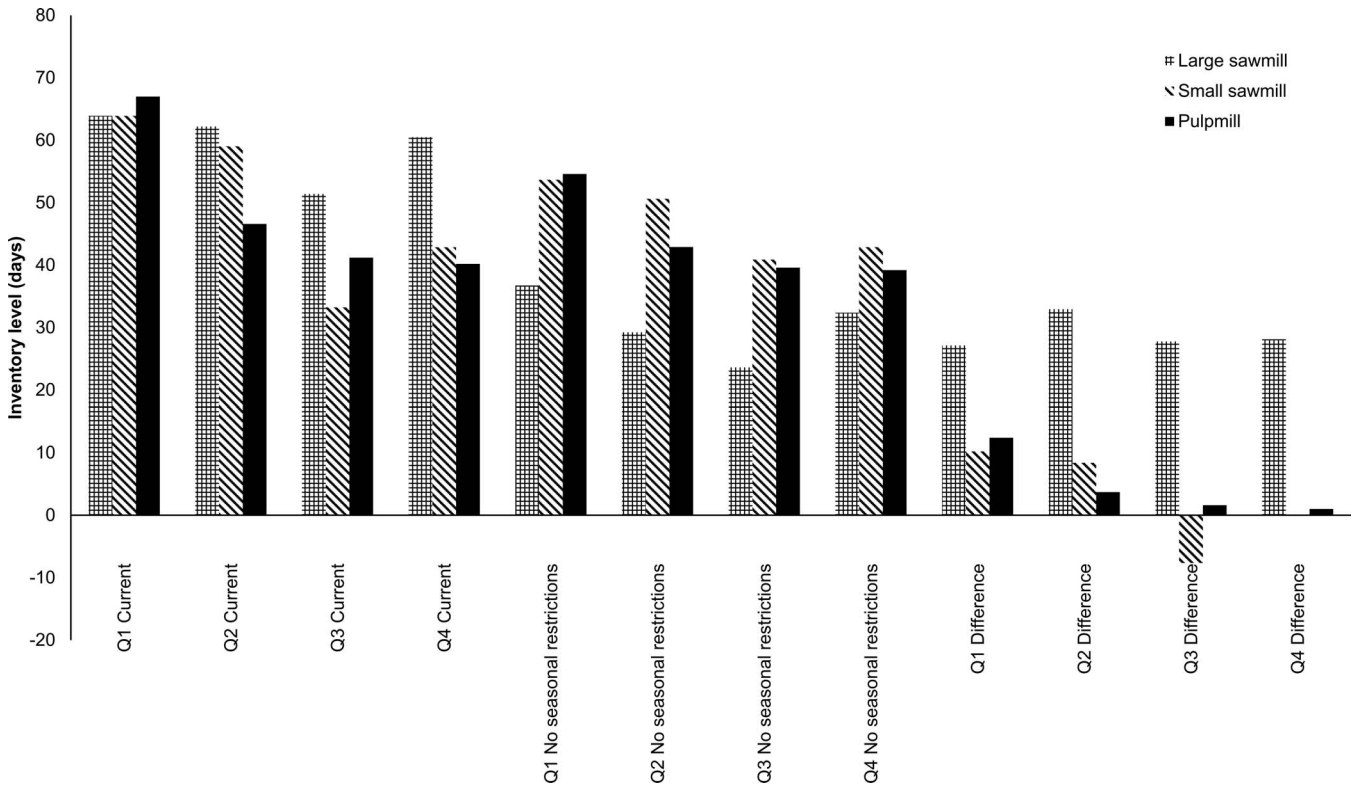

Figure 2.—Peak quarterly inventory currently, if seasonal timber harvesting restrictions (STHRs) did not exist, and the difference between current quarterly inventory levels and what would be necessary absent STHRs.

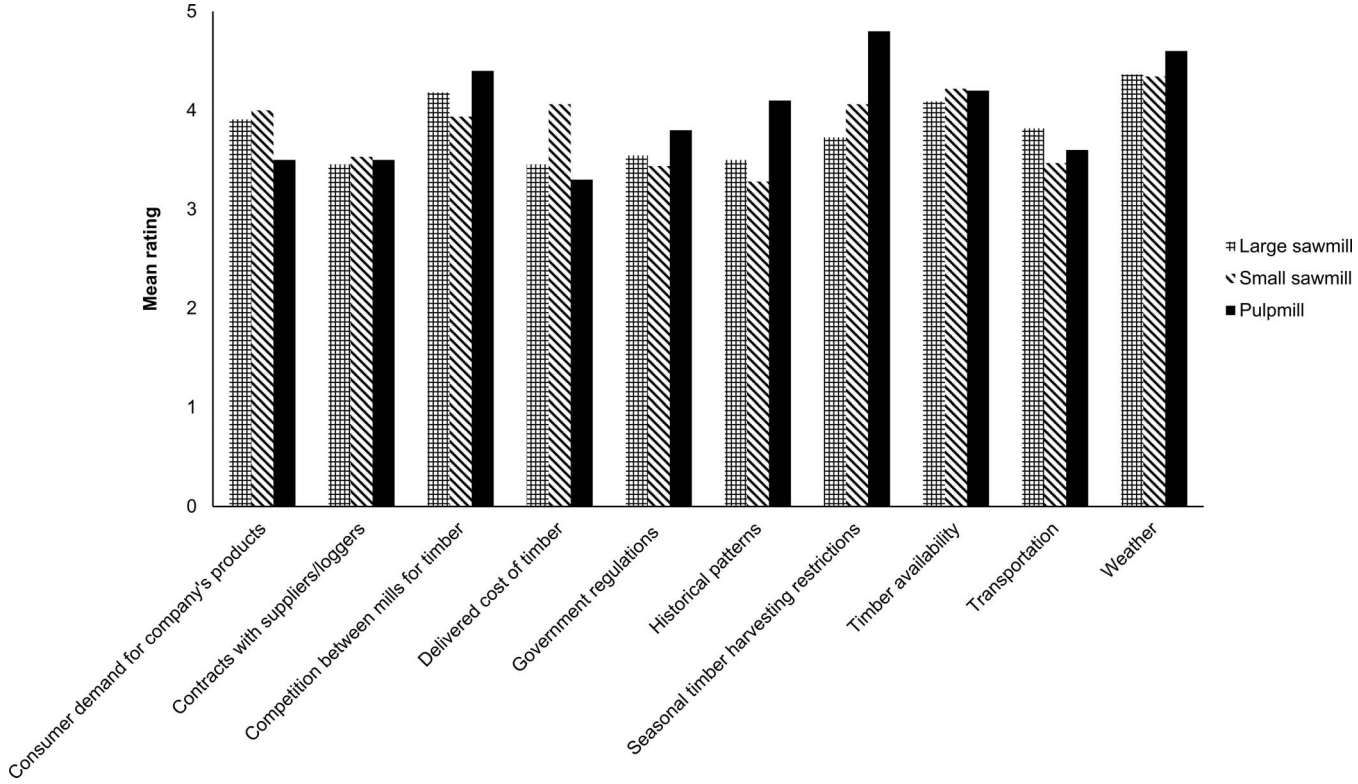

Figure 3.—Mean rating of factors influencing inventory levels at Wisconsin mills (1 = not important, 5 = very important). Government regulations exclude seasonal timber harvesting restrictions (STHRs).

The largest cost associated with STHRs for pulp mills and small sawmills resulted from increased inventory (Table 3). For pulp mills, increased inventories cost each firm an average of over \$1.7 million, or \$3.55 ton^{-1} of annual wood consumption. For small sawmills, the average per-firm cost of increased inventories was \$84,167, or \$3.25 ton^{-1}. Satellite wood yards cost pulp mills an average of \$706,250, or \$1.11 ton^{-1}. For small sawmills the second-largest cost incurred from STHRs was reduced wood quality resulting from extended storage, which cost \$49,444, or \$4.14 ton^{-1}. In total, pulp mills estimated that STHRs cost an average of \$2.7 million per firm (\$4.93 ton^{-1}) and small sawmills reported an average cost of \$188,888 per firm (\$10.33 ton^{-1}).

The total cost of STHRs to Wisconsin's forest industry was estimated to be \$57.6 million. The total cost is based on 2.4 million tons of sawtimber and 6.6 million tons of pulpwood harvested annually incurring self-reported STHR costs of \$10.33 ton^{-1} and \$4.93 ton^{-1}, respectively.

Pulp mills rated access and transportation restrictions as the most impactful type of STHR (Table 4). Access and transportation restrictions often limit availability of timber

Table 3.—Mean (standard error) cost of seasonal timber harvesting restrictions (STHRs) to forest products industry mills in Wisconsin.[a]

Type of cost	Mill type	Mean (SE) cost (\$)	Mean (SE) cost per ton (\$)	% reporting cost
Increased inventory	Small sawmill	84,167 (51,914)	3.25 (1.99)	39
	Pulp mill	1,671,250 (523,946)	3.55 (1.54)	100
Satellite wood yards and increased transportation costs	Small sawmill	9,444 (5,588)	0.48 (0.28)	22
	Pulp mill	706,250 (239,148)	1.11 (0.35)	88
Down-time or reduced production	Small sawmill	45,833 (18,100)	2.46 (0.95)	50
	Pulp mill	0 (0)	0 (0)	0
Reduced wood quality from extended storage	Small sawmill	49,444 (41,060)	4.14 (2.49)	44
	Pulp mill	111,875 (43,243)	0.15 (0.06)	50
Personnel costs	Small sawmill	0 (0)	0 (0)	0
	Pulp mill	12,500 (8,539)	0.02 (0.01)	13
Other costs	Small sawmill	0 (0)	0 (0)	0
	Pulp mill	150,000 (102,470)	0.10 (0.07)	13
Total costs	Small sawmill	188,888	10.33	
	Pulp mill	2,651,875	4.93	

[a] Small sawmill = <50,000 tons. A small number of large sawmills responded to this question, and therefore those responses are excluded.

sales to frozen or dry conditions because of concerns over forest roads or other difficulties accessing a tract. Large sawmills reported that oak wilt restrictions had the greatest negative impact. Small sawmills reported that seasonal road weight restrictions had the largest negative impact. Seasonal weight limits prohibit transportation of timber from most timber sales for approximately 6 to 8 weeks during spring, typically beginning in mid-March.

Respondents reported that, on average, each STHR increased delivered prices between 0 and 10 percent (Fig. 4). These values were highly variable, with a median response of zero for each restriction. Seasonal weight restrictions had the greatest impact on delivered prices, whereas heterobasidion root disease (caused by the fungus *Heterobasidion irregulare* [Garbel. & Otrosina]) restrictions were reported to have less of an impact than other restrictions.

Respondents were asked their opinions of STHRs as they are currently applied. The qualifier, as currently applied, was added after pretesting because several individuals pointed out that forest industry personnel recognize the need for STHRs, but restrictions are sometimes applied in instances when they are not necessary, thereby increasing costs for industry without protecting the resource. Therefore, the questionnaire noted that respondents should not consider their answers to indicate support or opposition to STHRs generally, but rather as applicable to how restrictions are currently applied.

Pulp mills disagreed with the notion that STHRs are a cost-effective method of protecting the environment ($P < 0.01$); the response from sawmills was not statistically different from neutral ($P > 0.05$; Table 5). Pulp mill ($P < 0.01$) and small sawmill ($P < 0.01$) median responses were significantly different from neutral, indicating that they agreed that STHRs had increased the cost of delivered wood. Ninety percent of pulp mills suggested that STHRs make Wisconsin's forest industry less competitive. Half of sawmills and 70 percent of pulp mills disagreed with the statement that STHRs benefit Wisconsin's forest industry, although the median responses were not statistically different from neutral ($P > 0.05$; Table 5). More respondents disagreed than agreed with the idea that the restrictions benefit Wisconsin landowners, although the median response was not different from neutral ($P > 0.25$).

Discussion

Procurement practices

Many of Wisconsin's pulp mills are located in central Wisconsin, whereas much of the timber is harvested in the northern one-third of the state (Virginia Tech Center for Natural Resources Assessment and Decision Support [VTCENRADS] 2016). Mills were located adjacent to rivers in central Wisconsin when transportation dynamics and the forest resource were much different from today. The current location of pulp mills forces them to purchase timber more than 100 miles from the mill and incur transportation costs that are higher than in other regions (Gibeault et al. 2015).

Table 4.—Mean and median rating of nine seasonal timber harvesting restrictions (STHRs) on Wisconsin mills (1 = large negative impact, 5 = large positive impact) and the percentages of respondents reporting positive and negative impacts from each restriction.

Restriction	Mill type[a]	% positive	% negative	Mean/median response[b]
Seasonal weight limits	Large sawmill	0	82	1.64/1.00* A
	Small sawmill	17	73	2.23/2.00* A
	Pulp mill	10	90	1.90/2.00* A
Access and transportation	Large sawmill	0	80	2.00/2.00* A
	Small sawmill	17	69	2.24/2.00* A
	Pulp mill	10	90	1.80/1.50* A
Oak wilt	Large sawmill	0	78	1.67/1.00* A
	Small sawmill	23	57	2.47/2.00 A
	Pulp mill	20	80	2.00/1.50 A
Pest restrictions (e.g., invasive species)	Large sawmill	0	60	2.20/2.00* A
	Small sawmill	17	53	2.70/2.00* A
	Pulp mill	10	80	2.40/2.00 A
Recreation restrictions	Large sawmill	0	40	2.60/3.00 A
	Small sawmill	17	50	2.63/2.50* A
	Pulp mill	10	80	2.10/2.00* A
Rare species and wildlife	Large sawmill	0	30	2.60/3.00 A
	Small sawmill	17	40	2.69/3.00 A
	Pulp mill	10	78	2.00/1.50 A
Soil and hydrological disturbance	Large sawmill	0	50	2.40/2.50 A
	Small sawmill	20	60	2.50/2.00* A
	Pulp mill	20	70	2.20/2.00 A
Cultural and archaeological	Large sawmill	0	20	2.80/3.00 AB
	Small sawmill	10	27	2.90/3.00 A
	Pulp mill	10	70	2.10/2.00 B
Heterobasidion root disease	Large sawmill	0	33	2.67/3.00 A
	Small sawmill	7	27	2.80/3.00 A
	Pulp mill	0	50	2.30/2.50 A

[a] Large sawmill = ≥50,000 tons; small sawmill = <50,000 tons.

[b] * = Median response was significantly different from no impact ($\tilde{x} = 3$) using the sign test ($\alpha = 0.05$). Responses in categories followed by the same letter are not statistically different using the Kruskal-Wallis test ($\alpha = 0.05$).

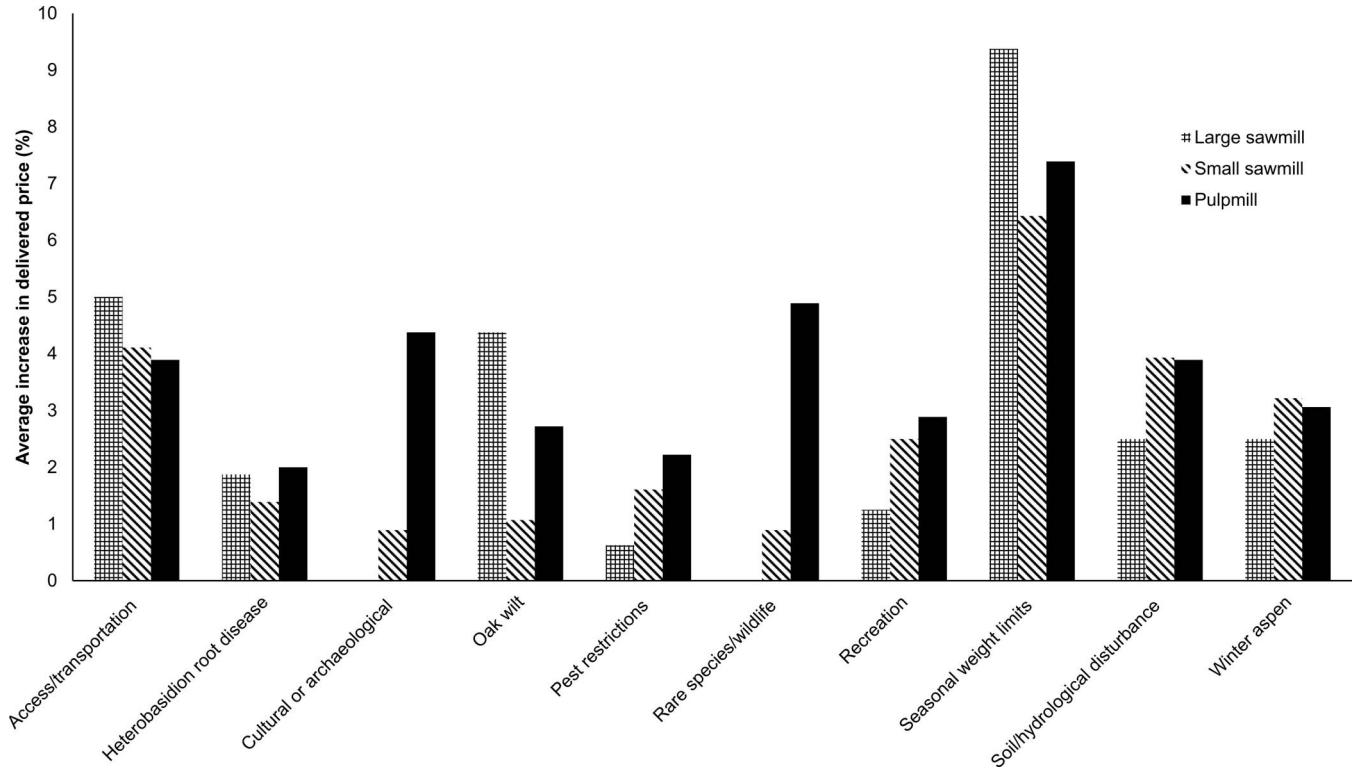

Figure 4.—Average reported increase in delivered prices (%) resulting from 10 seasonal timber harvesting restrictions (STHRs).

Table 5.—Forest industry representatives' views of seasonal timber harvesting restrictions (STHRs) as currently applied.

STHRs, as currently applied, are or have:	Mill type[a]	% agree	% disagree	Mean/median[b]
A cost-effective method of protecting the environment	Large sawmill	0	50	2.30/2.50 A
	Small sawmill	29	42	2.74/3.00 A
	Pulp mill	0	80	1.80/2.00* A
Increased the cost of delivered wood to this mill	Large sawmill	50	20	3.60/3.50 AB
	Small sawmill	69	13	3.66/4.00* A
	Pulp mill	100	0	4.70/5.00* B
Common on timber sales on private land in Wisconsin	Large sawmill	20	10	3.20/3.00 A
	Small sawmill	63	22	3.47/4.00* A
	Pulp mill	70	0	4.00/4.00* A
Common on timber sales on county and state forestland in Wisconsin	Large sawmill	50	20	3.30/3.50 A
	Small sawmill	72	3	4.09/4.00* AB
	Pulp mill	100	0	4.70/5.00* B
Benefit Wisconsin's forest industry	Large sawmill	0	50	2.40/2.50 A
	Small sawmill	25	50	2.66/2.50 A
	Pulp mill	10	70	2.10/2.00 A
Benefit Wisconsin' forest landowners	Large sawmill	10	30	2.70/3.00 A
	Small sawmill	32	39	2.90/3.00 A
	Pulp mill	20	60	2.60/2.00 A
Benefit the health of Wisconsin's forests	Large sawmill	0	33	2.56/3.00 A
	Small sawmill	41	28	3.19/3.00 A
	Pulp mill	20	60	2.50/2.00 A
Benefit wildlife and increase the environmental services provided by forests	Large sawmill	0	50	2.40/2.50 A
	Small sawmill	19	34	2.75/3.00 A
	Pulp mill	10	60	2.30/2.00 A
Make Wisconsin's forest industry less competitive in the marketplace	Large sawmill	40	10	3.50/3.00 AB
	Small sawmill	47	19	3.44/3.00 A
	Pulp mill	90	0	4.50/5.00* B

[a] Large sawmill = ≥50,000 tons; small sawmill = <50,000 tons.

[b] Responses were given on a 5-point Likert scale (1 = strongly disagree, 5 = strongly agree). * = Median response was significantly different from neutral ($\bar{x} = 3$) using the sign test ($\alpha = 0.05$). Responses followed by the same letter are not statistically different using the Kruskal-Wallis test ($\alpha = 0.05$).

Small sawmills had the smallest procurement radii, averaging 75 miles (Table 1). By comparison, sawmills purchased 90 percent of their raw material from within 70 miles of their facility in the northeastern United States (Anderson and Germain 2007) and from within 75 miles of the mill in the New England–New York region (Egan and Morin 2010). In the US South, TimberMart-South (2016) reported that loggers transported timber an average of 51 miles to mills, which is indicative of procurement radii similar to those of small sawmills in Wisconsin.

Mills' reliance on short log lengths is somewhat unique to the Lake States region and results in high timber handling costs (Gibeault et al. 2015). Most pulp mills in Wisconsin were built when manual timber harvesting necessitated short log lengths and many mills are still unequipped to handle tree-length material. The Scribner log rule (Staebler 1952) is the most commonly used log rule in the state. The Scribner log rule fails to account for stem taper and therefore underestimates board foot volume on long logs (Staebler 1953) and incentivizes loggers to deliver short logs to mills. Furthermore, the widespread adoption of cut-to-length harvesting systems (Rickenbach et al. 2015) means that loggers are well equipped to deliver short log lengths.

Forestland ownership and forest industry structure changed significantly since the last study of procurement practices in Wisconsin. As recently as the 1990s, 17 major forest products companies supplied at least 17 percent of their timber from fee land in the United States (Yin et al. 1998). Ten years later, almost all of those companies had sold their timberland (Hickman 2007). In 2015, pulp mills harvested zero volume from their own land in Wisconsin (Table 2). Nonetheless, sawmills still relied on company land to supply approximately 2 to 5 percent of their raw material. Purchasing gatewood from independent loggers has been the most common procurement strategy since at least the 1980s and the percentage of timber from this source has increased since then (Stier et al. 1986). Procurement through wood dealers and brokers is less common in Wisconsin than in the US South, where nearly half of loggers in some states operate through a wood dealer (Conrad et al., in press).

Inventory levels and wood availability

Seasonal inventory patterns have changed little over the past 30 years. Stier et al. (1986) reported seasonal patterns similar to those observed in our study and found that mills maintained a 2- to 3-month supply of timber. Because of spring breakup weight restrictions and the inaccessibility of many sites during spring, most mills build inventory during winter when logging conditions are at their best, and draw down inventories during the second quarter. STHRs, such as those motivated by oak wilt, also come into effect during the second quarter, which restricts timber supply during this period. Seasonal inventory patterns were similar in the Northeast, but inventory levels were generally lower there (Todd and Rice 2005). Peak inventory levels for pulp mills in our study averaged over 60 days during the first quarter (Fig. 2), whereas only two mills in the Northeast reported 60 days of inventory at any time during the year. Likewise, peak inventory levels exceeded 30 days in each quarter in Wisconsin, whereas the majority of northeastern pulp mills reduced inventories below 20 days during the second and third quarters. Southern pulp mills averaged less than 2 weeks of inventory during each quarter (Ulmer et al. 2004). Southern sawmills held 21 to 28 days of inventory during the first and fourth quarters and 14 to 21 days of inventory during the second and third quarters. Gibeault et al. (2015) documented that costs associated with wood transfers and seasonally high inventory levels contribute to high pulpwood delivered costs in Wisconsin.

The perceived decline in timber availability and quality is somewhat counterintuitive, and of concern for forest industry competitiveness. Wisconsin's forestland area has continued to increase over the past decade (Perry 2015) and timber volume in Wisconsin has been increasing since the 1980s, including significant increases in large-diameter classes (Perry et al. 2012). Furthermore, timber harvests in the state actually declined during the past 10 years (Haugen 2013). These findings suggest that over the past 10 years forest area has increased, timber volume has increased, but timber availability has declined and prices have increased. Similar perceptions were documented in the Northeast (Anderson and Germain 2007).

The average Wisconsin forest landowner owns just 26 acres, and landowners' primary motivations for owning forestland relate to aesthetics and hunting or fishing, not timber production (Perry et al. 2012). A recent study found that one-fifth of Wisconsin's forestland is held in parcels smaller than 20 acres, but less than 2 percent of timber harvests occurred on these parcels (VTCENRADS 2016). It appears that much of the increase in timber volume is located on ownerships that are not commonly harvested because of factors such as parcel size and landowner objectives.

Forest products mills rely on independent loggers to harvest and deliver timber to their mills. Over the past 15 years, Wisconsin has lost approximately one-third of its logging businesses and is struggling to attract new logging firms (Rickenbach et al. 2015). Weather and STHRs not only affect inventory levels, but also logging capacity utilization (Conrad et al. 2017). Mills' estimate of logging capacity utilization of 70 to 80 percent agrees with recent research in the Lake States (Taylor 2007, G.C. and Potter-Witter 2011, Conrad et al. 2017). Mills' accurate estimate of logging capacity utilization is encouraging because it implies that the industry recognizes the challenges of suppliers.

The frequency with which loggers were placed on quotas agrees with loggers' reports of lost production (Conrad et al. 2017). For the years before the survey, weather and market conditions meant that restrictive quotas were applied less frequently than in a study in the US South and Maine when loggers were placed on restrictive quotas 36 percent of the time, or nearly 19 wk/yr (Ulmer et al. 2004).

Industry response to STHRs

Small sawmills reported the highest per-ton costs because of STHRs. The higher per-ton costs may be due to the narrow range of product specifications and higher delivered prices paid for raw material. For example, a sawmill that purchased primarily oak would be affected by oak wilt restrictions much more than a pulp mill that relies on a mix of species. In addition, because sawmills produce solid wood products, they are generally more susceptible to financial losses from reductions in log quality resulting from extended storage, such as staining. Reductions in quality during extended storage was the second-largest STHR cost component for small sawmills (Table 3). Likewise, the

requirement to store timber for long periods could represent a greater financial burden for small sawmills than for larger organizations, especially if the need for long-term storage would be unnecessary absent STHRs. Finally, because delivered prices are higher for sawmills than for pulp mills, the same percentage increase in delivered prices resulting from STHRs would cause higher per-ton increases for sawmills.

STHRs increased pulpwood costs by 10 to 15 percent on the basis of survey responses and delivered timber prices at the time of the study (Gibeault et al. 2015, Resource Information Systems, Inc. [RISI] 2016). Delivered prices for sawtimber, especially hardwood sawtimber, are highly variable and not widely reported. Sawtimber stumpage prices ranged from roughly $40 to $100 per ton or more depending on species, grade, and location (Timber Mart North 2015). Assuming harvesting and transportation cost $20 to $25 per ton, stumpage prices are $40 to $100 per ton, and STHRs cost an average of $10 per ton (Table 3), STHRs increase raw material costs by approximately 10 to 15 percent. The percent increase in costs is likely similar for sawmills and pulp mills, but the impact may be more variable for sawmills because they generally target a smaller number of species and would not be affected by all species-specific restrictions (e.g., oak wilt, heterobasidion root disease; Table 3).

Seasonal road weight limits were considered most impactful, probably because this type of restriction affects all species and all mills within the state (Fig. 4). Because other restrictions do not affect all species and are generally applied to individual sites, they may not directly affect delivered prices. Restrictions on individual timber sales are likely to increase delivered prices indirectly by reducing timber supply during a portion of the year.

Access and transportation restrictions and oak wilt restrictions were also viewed negatively by responding mills (Table 3). Oak wilt restrictions are required on sales under the jurisdiction of WDNR officials, including sales on private land enrolled in the Managed Forest Law (MFL), a forest property tax incentive program (WDNR 2013). Oak/hickory (*Carya* spp.) is the most common forest type in Wisconsin, especially in the parcel sizes that are most likely to be harvested (Perry 2015). Guidelines in place at the time of the survey recommended avoiding harvesting timber in stands with $\geq$15 ft^2 acre^{-1} of oak basal area between early to mid-April and July 15 (WDNR and WCOF 2016). Oak wilt restrictions cover a large area and restrict harvesting for one-quarter of the year. Therefore, mills that require oak for their operations must increase inventory substantially before restrictions go into effect.

Access and transportation restrictions are applied at the discretion of the forester and landowner when the forest road system is vulnerable to damage or the site is accessed through an agricultural field, for example. Although not as widespread as seasonal road weight limits, access and transportation restrictions were applied to between 20 and 40 percent of private timber sales in Wisconsin according to harvest records and consulting and industry foresters (Conrad et al. 2017, Demchik et al. 2018). Therefore, it is reasonable to assume that mills incur costs from high inventory levels and associated reductions in timber quality from extended storage because of access and transportation restrictions (Table 3).

Although there has been little research on the cost of STHRs specifically, costs associated with increased inventory levels, satellite wood yards, and reduced wood quality from extended storage are well documented. Lang and Mendell (2012) reported that storing inventory for long periods increases operating costs. Linares-Hernandez and Wengert (1997) documented substantial losses in log value due to staining and checking when logs are stored for extended periods and recommended end coating some species to reduce losses. Wood sourced from satellite wood yards may cost as much as $10 ton^{-1} more than wood delivered directly to the mill (Martin 2001 as cited in Gallagher et al. 2008). Gibeault et al. (2015) found that the average delivered cost of hardwood pulpwood was over $10 ton^{-1} higher in the Lake States compared with the US South. They attributed much of this difference to high inventory levels, wood transfers resulting from seasonal supply constraints, and short-wood handling costs. Results of our study support the finding that STHRs impose significant costs on Wisconsin's forest industry.

Areas for improvement

Our results suggest that Wisconsin mills believe changes are necessary in the application of STHRs to protect the resource and allow for efficient timber utilization. Unfortunately, mills have limited options for addressing STHRs. In the short term, they have increased inventory levels to allow for continued operation during periods of limited timber availability. In addition, half of the small sawmills reported unwanted downtime because of STHRs (Table 3).

The decision to require STHRs is made by foresters, landowners, and in some cases state and federal regulators (Conrad et al. 2017). State and local governments apply spring road weight restrictions (WDOT 2016). State and federal regulations may limit harvesting seasonally to protect rare plants and animals. Restrictions to prevent oak wilt, heterobasidion root disease, and protect water quality may be required by the state if the property is enrolled in the MFL program (WDNR 2013). On the other hand, access and transportation restrictions and recreation-related restrictions are applied at the discretion of the forester or landowner. Having sold nearly all of their forestland, mills do not have the ability to harvest timber from their own land to supplement open-market purchases during periods of low timber availability (Table 2). Therefore, mills must rely on communication and advocacy to encourage landowners, foresters, and state officials to reconsider how STHRs are applied.

Recent research suggests that there are opportunities to protect the forest resource more efficiently (Conrad et al. 2017). Heterobasidion root disease restrictions are a good example of protecting forest resources while minimizing disruption and cost. Loggers have the choice to apply fungicides to stumps or harvest during winter to reduce the risk of heterobasidion root disease. When soil disturbance is a concern, instead of applying a STHR that limits access to certain times of the year or to ''dry or frozen'' conditions, the timber sale contract could specify unacceptable levels of soil disturbance (Conrad et al. 2017). Likewise, clearly specifying postharvest forest road conditions and requiring performance bonds to ensure compliance could render some access and transportation STHRs unnecessary. Finally, on multiunit timber sales, foresters should avoid including seasonally restricted harvest units in the same sale package

as units that can be harvested throughout the year. Mixing seasonally restricted units with those that can be harvested at any time forces the buyer to harvest the entire sale around the restricted period or move to the same sale twice, which increases harvesting costs because of an additional equipment move.

Finally, because STHRs are applied on the basis of foresters' professional judgment and landowner objectives (Conrad et al. 2017), additional research may aid foresters in deciding when STHRs are necessary. For example, research on soil disturbance after timber harvesting could be used to develop guidelines based on easily observed variables such as harvesting system, soil type, or habitat type. Cut-to-length systems travel on slash mats and have lower ground pressure than other systems, which should allow for a longer operating season. Likewise, some soil types are more susceptible to damage than others, and failing to consider this variable may result in unnecessary restrictions.

Summary and Conclusions

The forest products industry is a major employer in Wisconsin and the timber they purchase from landowners finances sustainable forest management. Therefore, it is important to understand the challenges faced by mills in procuring wood and document changes in practices over time. It is especially important to consider how forest management practices and STHRs affect forest industry at present because delivered pulpwood prices in Wisconsin have been among the highest in the country for the past several years (Gibeault et al. 2015, RISI 2017).

This study documented several challenges to Wisconsin's wood supply chain. First, the time and distance required to move timber from stump to finished product at the mill are long. The average procurement radius for pulp mills was over 120 miles, and past research confirms that transportation costs in the state are higher than in competing states (Gibeault et al. 2015). Second, in response to STHRs, mills are increasing inventories, relying on satellite wood yards, and experiencing reductions in raw material quality during extended storage. Although cost estimates provided in this study were self reported, past research confirms that these practices increase costs for mills. Third, although forest area and timber volume have increased in recent years (Perry et al. 2012), mills reported declines in timber availability. Recent research suggests that a significant percentage of timber volume is unavailable for harvest for a variety of reasons, including small parcel sizes and landowner objectives (VTCENRADS 2016).

Although Wisconsin's wood supply chain certainly faces challenges, there are reasons for optimism. The state has a strong and diverse forest products industry, as evidenced by the state's status as the number one paper producer in the United States (WDNR 2016) and the variety of sawmills that responded to the survey. In addition, the state has more than 17 million acres of forestland with growth exceeding removals by a wide margin (Perry 2015). Finally, although STHRs have imposed costs on Wisconsin mills, they reflect a desire by policy makers, foresters, and landowners to sustain the forest resource for the long term. Additional research and consistent communication between landowners, foresters, and the forest industry are needed to ensure that STHRs are applied appropriately to ensure resource sustainability while minimizing costs to the wood supply chain.

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