Utilization of Fire-Impacted Timber: A Summary of a Survey of Mill Procurement Personnel and a Review of the Literature

Isaac C. Harberts[1], Charles R. Blinn[2], Kyle G. Gill[3] and Lane B. Johnson[3]

[1]Formerly with University of Minnesota, Department of Forest Resources

[2]University of Minnesota, Department of Forest Resources

[3]University of Minnesota, Cloquet Forestry Center

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For more information about the Department of Forest Resources and its teaching, research, and outreach programs, contact the department at: Department of Forest Resources at the University of Minnesota.

115 Green Hall
1530 Cleveland Avenue North
St. Paul, MN 55108-6112
Phone: (612) 624-3400
Fax: (612) 625-5212
Email: frweb@umn.edu
Webpage: https://forestry.umn.edu/

Executive Summary

Wildfire is an important ecological process and prescribed fire is a critical tool for the stewardship of fire-dependent forest lands. Continued interest in the use of prescribed fire as part of various silvicultural systems raises the question: **How does fire-impacted timber influence timber utilization by mills?** To help answer that question, a survey of mill procurement staff in the Lake States (Michigan, Minnesota and Wisconsin) and the southeastern US and a literature review were conducted.

When it comes to utilizing fire-impacted timber, the "answer" is situation dependent on what the mill produces and their outlets for residual products. Charred wood and bark negatively impact the quality of products manufactured from pulpwood (e.g., paper, fluff pulp, cardboard) as small discolored flecks can appear in the final product. Utilization by mills which produce dimensional lumber generally isn't a concern as the charred material can be removed by the debarking and slabbing processes. However, char-damaged wood fibers can result in weaker strength solid wood products.

When considering the use of prescribed fire in a timber stand, it is important to consider local markets and their procurement specifications for fire-impacted timber. Waiting several years after a prescribed fire before harvesting timber may increase its utilization.

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Introduction

Fire and its use in forest management

Fire has influenced ecosystem processes for millennia (Bowman et al. 2011). The origin of fire is tied to the origin of plants, which are responsible for two of the three elements essential to the existence of fire: oxygen and fuel (Bond et al. 2005). The third element, a heat source, has been available throughout the history of Earth mainly through lightning, but also from volcanoes, sparks from rock falls, or meteorite impacts. In North America, humans have been a component of fire regimes for at least the last 12,000 years (Ellis et al. 2021). Only in the 20th century have humans become capable of modifying fire regimes through fire suppression technology. This new human relationship with fire has reshaped fire regimes and many terrestrial plant communities making fire-prone landscapes more susceptible to uncharacteristically high-severity fire at large spatial scales, and the conversion of fire-adapted plant communities to fire-intolerant vegetation compositions.

Since 2000, an annual average of 70,600 wildfires have burned an annual average of 7.0 million acres in the US (Hoover and Hanson 2021). This figure is more than double the average annual acreage burned in the 1990s (3.3 million acres), although a greater number of fires occurred annually in the 1990s (78,600 average). Twelve of the years after 1999 have had a higher number of acres burned by wildfires than in any of the preceding 20 years (Figure 1) (National Interagency Fire Center, 2021).

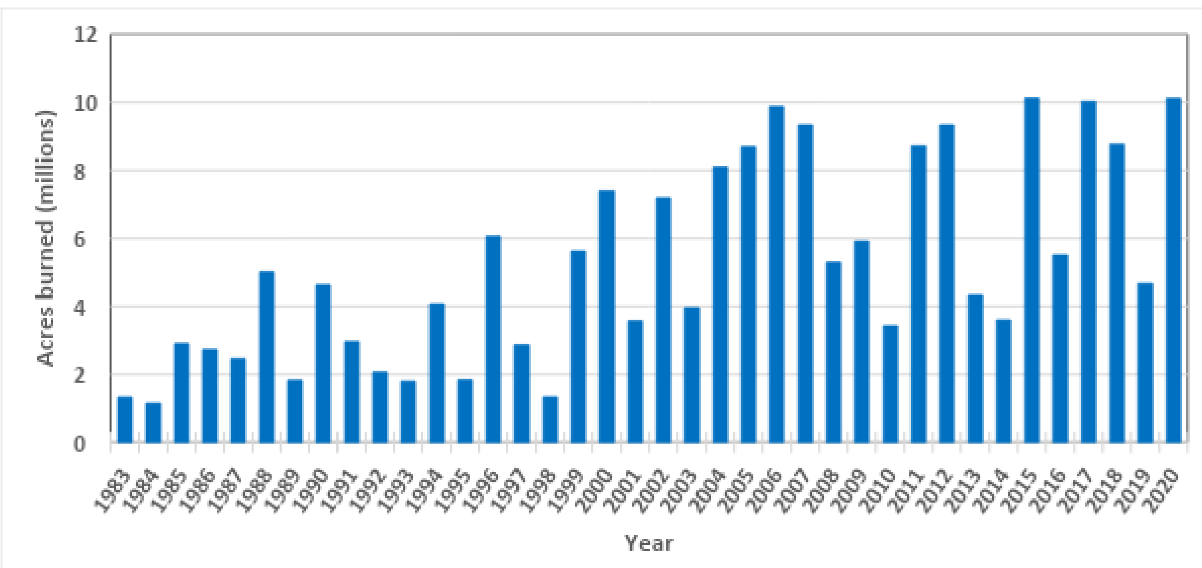

Figure 1. Annual number of acres burned in wildfires, 1983-2020 (National Interagency Fire Center, 2021).

Prescribed fire (prescribed burns, controlled burns, planned fire) and managed wildfire are important management tools used to accomplish specific forest management goals. Native Americans used fire in oak and pine savannas to maintain those cover types, improve access and hunting and eliminate brush and timber so that they could farm areas (Wade and Lunsford 1988, Ryan et al. 2013). Today, prescribed fire is used within forest management for many purposes such as reducing wildfire hazards, restoring and maintaining ecosystems, improving wildlife habitat, creating conditions favorable for tree regeneration (e.g., seedbed preparation) and canopy recruitment, preparing sites for planting, recycling nutrients back to the soil, minimizing the spread of pest insects and disease and reducing plant competition (Walkingstick and Liechty n.d.).

Increasing the use of prescribed fire in fire-dependent (FD) forests and woodlands (Aaseng et al. 2003) in the Lake States is often discussed due to the increasing recognition of the relationship between fire, humans as primary ignition sources, and ecosystem development and succession (Larson et al. 2021). Fire and its frequency of return has a direct relationship on the likelihood that a FD community is expressing the xeric, or pyrogenic, components of the system. Known pyrogenic plant species include red pine, jack pine, blueberry species, wintergreen, bush honeysuckle, and bracken fern.

When fire is absent from a FD system, vegetation less adapted to frequent fire, such as hazelnut, balsam fir, and red maple, outcompete the pyrogenic species. This can have one of two effects. One possible developmental process is that fuel builds up over time such that, when a fire ignites, it creates an increased likelihood of high-severity fire. A second potential effect is an increased likelihood of a successional shift towards a mesic community that no longer has the components of an FD system. Recent research highlights the long-term role humans have played as a primary ignition source that intentionally brings the fire component into FD systems (Kipfmueller et al. 2021). This suggests that contemporary land managers will likely need to be the ignition source that returns fire to the community. Using prescribed fire as an occasional disturbance process, in conjunction with timber harvesting and other forest stewardship techniques, supports both known and unknown pyrogenic components of FD systems that contribute to the biodiversity and ecological integrity of these systems now and into the future.

Utilization of fire-impacted timber

There is a perceived stigma surrounding the use of fire-impacted timber in the timber industry, and whether or not mills will accept fire-charred bark or fire-charred timber. When the objective for an area includes timber production, it is important to consider the main concerns mills have surrounding the quality and characteristics of fire charred-wood or bark in their manufacturing process. From this, the economic impacts of charred-wood or bark on paper products, dimensional lumber, fabricated building materials, and residual products can be inferred.

Mill procurement staff directly influence the characteristics and quality of products at their mill through the timber they purchase. Because of this, procurement operations must ensure the timber they purchase meets the mill's specifications to ensure product quality. The standards for timber quality and characteristics are determined by the products the mill manufactures. When the injury to the tree caused by the fire is severe enough, it is likely to extend through the bark and into the wood of the tree. Thus, fire can degrade the structural and visual integrity of the wood, and as a result impact it's suitability for a mill's end product. Budi (2001) identified the following different abnormalities which decreased physical or mechanical wood properties following a fire.

1) creating smaller but denser pores than normal in a concentric pattern,
2) changing dimension and numbers of axial parenchyma,
3) producing more axial intercellular canals,
4) forming decay spots in the wood,
5) creating the concentric area of fibers or forming the vessels late,
6) creating new calluses and the bole losing its cylindrical form,
7) producing abnormal gums in the wood and
8) hollowing of the bole.

The impact of an injury to a tree is dictated by the size of the injury, tree size and the period of time the timber is left standing after the injury occurs (Watson and Potter 2004, Pausas 2014). It is important to consider the degree of damage to the physical characteristics of the tree. If standing timber has been impacted all the way through the bark and the cambium is affected, the moisture content of the inner wood will be greatly reduced if it is not removed (Watson and Potter 2004). Potentially, fire-charred timber, especially smaller diameter trees, can lose value for many products due to wood drying and decay if it is not harvested relatively soon (Watson and Potter 2004). Fungi that infect tree boles through both logging and fire scars can cause a substantial reduction in value and degrade timber quality over several decades (Hesterberg 1957).

Watson and Potter (2004) reported that burned timber must be harvested and utilized within one year to maintain the value of lumber products. According to a study within oak forest types in southern Missouri, multiple fires over a tree's lifetime caused a slight reduction in merchantable lumber value and volume if fire damage was less than 50 cm in height and 20 percent of basal circumference (Marschall et al. 2014). However, they reported that if those thresholds are exceeded, value loss is likely and would increase over time unless trees were harvested within about five years after the fire damage occurred.

A West Virginia study which analyzed the visual quality of 79 fire-impacted hardwood trees (nineteen red maple, twenty-one red oak, sixteen white oak, twenty-three yellow-poplar) determined that there was little impact to value when damage was through the bark into the wood for 69 of those trees, including defects such as black bark, bark sloughing, cat faces, and butt scars (Wiedenbeck and Schuler 2014). However, the other ten trees (seven red maple, two red oak, one white oak) lost between ten and thirty percent of their value due to the presence of large cat faces on each of the tree's butt logs (Wiedenbeck and Schuler 2014). Thus, if a tree is impacted through the bark to the wood, there will be a significant loss in terms of value, but if the char is limited to the bark, the tree retains a greater overall value since the integrity of the wood is retained.

Dey and Schweitzer (2018) reported that larger diameter oak trees are harder to scar from a fire and still merchantable due to their thicker bark. They reported that fire scars toward the base of the butt log of a larger diameter tree are often outside of the scaling cylinder of a sawlog and thus don't impact product recovery or value. However, fire scars in pole and small sawtimber-sized oak trees are more likely to be impacted by wood decaying fungi as those trees will likely remain in the stand longer. Basal scars may be removed from a log in the woods through bucking practices. But, inwoods bucking may cause an unnecessary reduction of volume as much of the defect that might be bucked may be removed during the slabbing process within the sawmill.

Mann et al. (2020) evaluated the potential economic effects of prescribed fire on oak sawtimber volume and value across 138 stands where between one and six prescribed fires had occurred. They reported that the total loss in volume ranged from 0 to 2,269 board feet/acre and that the loss in butt log volume ranged from 0 to 1,684 board feet/acre. Volume losses were greatest on south-facing slopes, particularly as the number of prescribed burns increased. The value loss ranged from $0 to $272.95/acre.

Of greatest importance to mills is the merchantability of timber. Fire-charred material may cause a noticeable impact on a mill's product quality. The type of product that a mill is producing is a contributing factor for whether charred-bark is an issue, and it can vary between mills of the same production types (Watson and Potter 2004). Char is especially important to avoid in paper and pulp production of high-quality white paper (Araki 1999, Dyson 1999, Minnesota Forest Resources Council 2013). Due to the need to use chemicals to remove any discoloration as well and to add non-charred filler material, pulp and paper procurement staff do not purchase fire-impacted timber. Because of this, there is a noticeable impact on the marketability of charred materials to any mills directly involved in the paper making process. By adding fire-charred materials to the pulp the overall paper quality is lowered (Watson and Potter 2004). Araki (2002) reported that two years following a wildfire, chips from small diameter burned conifers had moisture contents that were too low for pulping.

Fire-impacted bark is of lesser concern to the dimensional lumber industry because the timber is debarked and if damage has extended into the xylem, the butt log can be cut off in order to retain a higher grade (Marschall et al. 2014). In a study of 54 hardwood timber stands located within the Hoosier National Forest in Indiana where prescribed fire had been used, more trees were scarred, the relative volume loss increased and a higher percentage of trees declined in tree grade as the number of prescribed fires increased (Stanis et al. 2019). However, in that study, there was less than 10 percent sawtimber volume loss in burned stands and less than 3 percent of trees had a reduction in tree grade.

Fabricated building material production like oriented strand board (OSB) has been able to utilize fire-charred wood in their processes more, with reported findings that fire-charred wood chips do not significantly impact the strength of the board when used as an additive to the mixture of chips (Moya et. al 2008). However it was noted that the use of fire-charred bark and bark in the mixture were responsible for significant loss in strength (Moya et. al 2008). Fire-charred wood may be used in plywood to add aesthetic value but there is little available literature investigating the structural integrity of this particular use.

The US Forest Service and the Joint Fire Science Program Fire Science Exchange Network conducted a webinar entitled "Prescribed Fire and Timber Management" as a part of a "Fueling Collaboration Panel Discussion Series" in 2021. It discussed fire injury, value and volume loss, focusing on oak sawtimber-size trees. The video is accessible at https://www.youtube.com/watch?v=su_nKNVPx7s with resources and publications available at https://www.nrs.fs.fed.us/webinars/fueling/4/.

The relationship between fire, residual char on bark or wood, and pine timber merchantability in the Lake States (Michigan, Minnesota, and Wisconsin) is not clearly understood. We explored this relationship through both a survey of mill procurement staff and a literature review. The survey of mill procurement staff was conducted to better understand how the presence of fire-impacted bark and wood affects the procurement and use of timber in various wood consuming mills in a) the Lake States, where prescribed fire is rarely used in conjunction with timber production goals and b) the southeastern US, where prescribed fire is perceived to be used in conjunction with timber production and other goals (Southern Group of State Foresters 2014). The literature review was conducted to explore foundational aspects and understanding of fire, particularly its physical and chemical effects on bark and wood and how that impacts utilization of that resource.

Definition of Terms

The following terms used in this paper are defined below. Images depicting some of the terms are presented in Figure 2.

Fire injury - a tree's biological response to prescribed fire that may or may not manifest itself as an impact to tree utilization (e.g. crown scorch).

Fire damage - the modification of timber quality due to injury from wildfire or prescribed fire.

Fire-impacted bark - when the bark (phloem) but not the wood (xylem) of a tree is scorched and modified by fire.

Fire-impacted wood - when fire damage to a tree extends beyond the bark (phloem) into the wood (xylem) of the tree. Often it is only the butt log of a tree that becomes fire-impacted, sometimes through repeated injury, or the long-residence time of a fire at the base of the tree.

Fire-charred timber - trees with bark or wood impacted by wildfire or prescribed fire explicitly managed for the purpose of utilization by the forest industry.

Mill Utilization Survey

Several mills in the Lake States and southeastern US were contacted to learn more about the procurement of fire-charred timber used in the manufacture of a variety of forest products.

Approach

The survey contained questions about the respondent's and mill's demographics, and the mill's specifications governing the procurement of fire-damaged timber. A draft of an introductory script and survey were shared with a staff member of the Forest Resources Association (FRA) with modifications made in response to comments received. The Institutional Review Board at the University of Minnesota reviewed the final introductory phone script (Appendix 1) and survey (Appendix 2) and determined that the study was not research involving human subjects.

Figure 2. Left: Fire-impacted bark and wood on the bole of a red pine. This type of injury degrades the quality of the butt log, but may not have negative impacts to wood quality above the height of the visible fire damage. Right: Fire-impacted bark on the bole of a red pine with no visual evidence of fire-impacted wood.

The survey was conducted between March - July, 2020. A study team member made the first contact with Minnesota mill procurement staff over the phone and the FRA staff person or a study team member made the initial contact with mills in other states via email. Respondents could either provide their responses in an emailed copy of the survey or through a phone interview. Phone interview responses were recorded and then responses were transferred to a digital copy of the survey. All survey responses were entered into an Excel file and all entries were error checked.

Basic summary statistics were calculated using Excel. For most questions all responses were lumped together. For some questions, respondents were separated into the two product categories of a) pulp products (i.e., white paper, brown paper, cardboard and fluff pulp) and b) solid wood products (i.e., lumber; oriented strand board (OSB); siding; pellets; and poles, cabin longs pilings and posts). A respondent who indicated that their mill manufactures both brown paper and lumber was categorized in the pulp product category as their wood procurement specifications were similar to that group. Separate analyses were also conducted for some questions to compare Lake States and southeastern US responses. Respondents and their company affiliations have been kept confidential due to the proprietary nature of some of the information shared.

Results

<u>Respondent and mill demographics – All respondents lumped together</u>

A total of 31 mills were contacted. Responses were received from procurement staff at 18 mills. Of those 18 mills, four were in Georgia; four in Wisconsin; three in Alabama; two each in Florida, Louisiana and Minnesota; and one in Mississippi. All respondents indicated that they procure timber and influence the mill's manufacturing process through their identification of suppliers, price paid, volume purchased, timber quality and wood form. Their procurement impacts their mill(s) operations through volume purchased and the quality of that wood.

A summary of the number of mills by the product manufactured is shown in Table 1. Brown paper was the most commonly cited product. No mills reported manufacturing plywood. Nine respondents (50 percent) reported that their mills manufacture only one product. Twelve respondents (67 percent) were categorized as producing a "pulp" product and six produced a "solid wood" product.

Fifteen of the 18 mills purchased pine (Table 2). Only two mills purchase a single species. A few mills (three or fewer) purchased maple, aspen, spruce, southern hardwoods (oak, hickory, sweetgum, yellow poplar), fir, cherry, elm, ironwood, mixed hardwoods, tamarack and yellow and paper birch.

Table 1. Number of responding mills by product(s) manufactured and category (pulp or solid wood product) (n = 18).

Number of responding mills	Product(s) manufactured	Product category
3	Only brown paper	Pulp product
2	Only cardboard	Pulp product
2	Only lumber	Solid wood product
1	Only white paper	Pulp product
1	Only oriented strand board (OSB)	Solid wood product
1	Only pellets	Solid wood product
1	Both brown paper and lumber	Pulp product*
1	Both brown paper and cardboard	Pulp product
1	Both white and brown paper	Pulp product
1	Both brown paper and fluff pulp**	Pulp product
1	Both oriented strand board and siding	Solid wood product
2	Only fluff pulp	Pulp product
1	Only utility poles, cabin logs, pilings, posts	Solid wood product

*This respondent was categorized in the pulp product category as their wood procurement specifications were similar to that group.
**Fluff paper is a type of market pulp used as an absorbent core in personal care products such as diapers and feminine hygiene products.

Table 2. Summary of species utilized by the products manufactured (n=18).

Product(s) manufactured	Species utilized										
	Various pine	Spruce	Fir	Tamarack	Aspen	Mixed hardwoods	Birch	Cherry	Ironwood	Elm	Maple
Pulp products											
Brown paper and lumber	X										
Cardboard	X										
Brown paper and cardboard	X										
White paper							X	X	X	X	
Brown paper	X										
Fluff pulp (2)	X										
Cardboard	X					X					X
White and brown paper	X					X					X
Brown paper	X					X					
Brown paper	X										
Brown paper and fluff pulp	X										
Solid wood products											
OSB and siding					X						
Utility poles, cabin logs, pilings and posts	X										
Pellets	X					X					
Lumber		X									
OSB	X			X			X				
Lumber	X	X	X								

<u>How fire-impacted wood influences the mill's process or end-product(s) – All respondents lumped together</u>

Respondents were asked to indicate how fire-impacted wood effects their manufacturing process or end product. Eight respondents (44 percent) indicated that it reduced their product quality (Table 3). White and brown paper, cardboard and fluff pulp were the products identified where product quality was reduced, most commonly through flecks which can appear in the final product, impacting its visual quality. For brown paper, more bleach was required. Those results are similar to what was reported by Watson and Potter (2004) who indicated that the most serious issue for bleached chemical and mechanical pulp mills is ensuring the removal of all carbon residues from their wood prior to it being chipped. Brown paper and some lumber require more cleaning and refining to ensure that the char does not appear in the finished product. Three respondents 17 percent) indicated that there was no impact for utility poles, OSB or pellets. One lumber manufacturer (6 percent) doesn't purchase fire charred timber. In addition, one respondent (6 percent) indicated that char adds black flecks to cardboard and brown paper and another (6 percent) indicated that yields are reduced by charred wood in the digester.

Table 3. Number of responding mills indicating how fire-impacted wood affects their manufacturing process or end-product. Respondents could identify more than one effect. Individual respondent comments appear in the footnotes (n = 18).

Number of responding mills	Effect on their process or end-product	Number of respondents by product category	
		Pulp products	Solid wood products
9	Reduces product quality[1]	8	1
2	Need to alter inputs to the process[2]	2	0
3	Additional need to clean the material[3]	2	1
6	Other impact[4]		
	None	0	3
	Do not purchase	0	1
	Adds black flecks	1	0
	Reduces yield	1	0

[1]The ways in which fire-impacted wood reduces product quality are by a) leaving visual specks (brown paper and lumber); b) no specification (OSB and siding); c) it may impact product quality if charred cambium presents visual issues (cardboard); d) it impacts visual quality (brown paper and cardboard); e) char will stain the product (white paper); f) it reduces absorbency (fluff pulp); g) it adds black flecks to product (cardboard); h) cannot use it for one product (white paper) and must bleach it to remove char for another product (brown paper); i) the char does not process and break down to individual fibers and creates visual impacts which effect product color and grade (fluff pulp); j) and it is not removed using bleach (fluff pulp).
[2]There is a need to alter the inputs for processing brown paper; it requires more bleach to remove (brown paper).
[3]There is an additional need to clean the material for lumber; possibly need to clean material more often so that it doesn't show up in the paper (although not a big issue in producing brown paper); and too much burned wood can cause a need to refine the product more (brown paper).
[4]Other responses were that it has no effect as long as the wood fiber is not charred (utility poles, cabin logs, pilings and posts); no impact (pellets); no impact (OSB); do not purchase fire-charred wood (lumber); charred wood adds black flecks to the product (cardboard); and reduced yield going through the digester (brown paper).

<u>Procurement of fire-impacted timber – All respondents lumped together</u>

None of the eighteen respondents indicated that their mill's specifications on the amount of fire-impacted wood have changed over time. Seventeen respondents (94 percent) indicated that they purchase fire-charred timber where the impact of fire is restricted to the bark. The other respondent (6 percent), a lumber producer, does not purchase fire-charred timber. Most commonly, fire-impacted timber is only purchased when the fire has charred the bark (phloem) but not the wood (cambium and xylem) of the trees (Table 4).

Table 4. Summary of mill specifications for the amount of fire-impacted bark allowed within a load of logs delivered to the respondents' mills (n = 17).

Number of responding mills	**Mill's specifications for the amount of fire-impacted bark allowed within timber delivered to the mill**	**Product(s) represented**	**Number of respondents by product category**	
			Pulp products	**Solid wood products**
10	Only the bark has been burned and the wood (cambium or xylem) have not been impacted	Brown paper and lumber; brown paper and cardboard; white paper; cardboard; brown paper (2); brown paper and fluff pulp; OSB and siding; utility poles, cabin logs, pilings and posts; OSB	7	3
2	Limit on the amount of wood on a truck or daily volume purchased	Cardboard; fluff pulp	2	0
1	Limits what they can do with the bark	Lumber	0	1
4	No specifications	Brown paper; cardboard; white and brown paper; pellets	3	1

Of the seventeen respondents who indicated that their mill purchases fire-impacted timber where the char is limited to the bark, sixteen respondents (94 percent) indicated that when they do purchase that timber, it is mixed in with all other loads received by the mill. A mill which manufactures lumber indicated that loads with fire-impacted bark are processed separately with other fire-impacted timber (because the char limits what they can do with the bark byproduct, they don't mix it in with non-impacted bark which they can sell; instead the fire-charred timber is batch processed and the bark residue is burned).

Four respondents (22 percent) indicated that their mill purchased timber where fire had affected both the bark and wood (Table 5). Of those four mills, two pulp-producing mills specify the maximum percentage of fire-charred bark and wood allowed in a load and two solid wood product mills require little decay or have the ability to peel off charred fiber (Table 6). A mill that produces both white and brown paper and purchases timber where fire has impacted both the bark and wood indicated that they only utilize this charred material in brown paper. Those four respondents (22 percent) indicated that loads with fire-impacted bark and wood are mixed in with all other loads received by their mill.

Table 5. Summary of mills that do or do not purchase timber where fire has affected both the bark and wood (n=18).

Number of responding mills	Mill purchases timber where fire has impacted both the bark and wood	Product(s) represented	Number of respondents by product category	
			Pulp products	Solid wood products
4	Yes	Cardboard; white and brown paper (but purchase for brown paper); Utility poles, cabin logs, pilings and posts; pellets	2	2
14	No	Brown paper and lumber; cardboard; brown paper and cardboard; white paper; brown paper; fluff pulp (2); brown paper (2); brown paper and fluff pulp; OSB and siding; lumber (2); OSB;	10	4

Table 6. Summary of mill specifications for the amount of fire-impacted bark and wood allowed within a load of logs delivered to the mill (n=4).

Number of responding mills	Specifications for the amount of fire-impacted bark and wood allowed within a load of logs delivered to the mill	Product(s) represented	Number of respondents by product category	
			Pulp products	Solid wood products
1	No effect on bark. As long as they can peel off charred fiber, they can still use log	Utility poles, cabin logs, pilings and posts	0	1
1	Wood must be solid with little decay	Pellets	0	1
1	Less than 15%	Cardboard	1	0
1	Less than 5%	White and brown paper (but specifications are only for brown paper)	1	0

Only one of the eighteen respondents (6 percent), a mill that produces lumber, indicated that something has changed in its process to utilize more fire-impacted timber over time. While that mill reported having purchased some fire-charred timber in the past, which was used as boiler, fuel, that procurement episode was in response to a large amount of burned timber in the area following a wildfire.

Where and how timber is assessed for the presence of fire-charred bark or wood – All respondents lumped together

Respondents may look for the presence of fire-impacted bark or wood at different locations to ensure that the wood delivered to their facility meets their specifications. Three respondents (17 percent) only assess for the presence of char before the timber is purchased, one only assesses in the woods before timber is hauled to the mill, and two only at the scale shack (Table 7). Twelve respondents (67 percent) assess for the presence of fire-impacted bark or wood multiple times with seven respondents (39 percent) assessing twice, two (11 percent) assess it three times, one (6 percent) assesses at four locations and two (11 percent) at five locations. On average, timber which goes into the manufacture of pulp products is assessed for the presence of fire-impacted bark or wood more often than solid wood products (average of 2.5 times vs. 2 times).

Table 7. Number of responding mills by the location where the presence of fire-impacted bark or wood is assessed (n = 18).

Number of responding mills	Number of inspection points	Location where presence of fire-impacted bark or wood is assessed	Product(s) represented	Number of respondents by product category	
				Pulp products	Solid wood products
3	1	Only in the woods before timber is purchased	Fluff pulp ; utility poles, cabin logs, pilings and posts; lumber	1	2
0	NA	Only in the woods before timber is harvested	None	0	0
1	1	Only in the woods before timber is hauled to the mill	OSB and siding	0	1
2	1	Only at the scale shack	Brown paper (2 respondents)	2	0
0	NA	Only in the woodyard	None	0	0
3	2	Both in the scale shack and woodyard	White and brown paper; cardboard; fluff pulp	3	0
3	2	Both in the woods before timber is purchased and at the scale shack	Brown paper and fluff pulp; pellets; OSB	1	2

1	2	Both in the woods before timber is hauled to the mill and within the woodyard	White paper	1	0
1	3	In the woods before timber is purchased, in the woods before the timber is harvested and at the scale shack	Brown paper and lumber	1	0
1	3	In the woods before timber is purchased, in the woods before the timber is hauled to the mill and at the scale shack	Brown paper and cardboard	1	0
1	4	In the woods before timber is purchased, in the woods before the timber is harvested, in the woods before the timber is hauled to the mill and at the scale shack	Brown paper	1	0
2	5	In the woods before timber is purchased, in the woods before the timber is harvested, in the woods before the timber is hauled to the mill, at the scale shack and within the woodyard	Lumber; cardboard	1	1

All respondents visually inspect for fire-impacted bark or wood. None make that assessment using scanners. One respondent (6 percent) who produces brown paper and cardboard and assesses for presence in the woods before a) timber is purchased and b) hauled as well as c) at the scale shack also uses a probe to inspect for fire-impacted bark or wood.

All respondents indicated that the wood is debarked at their mill before processing. Debarking is generally accomplished using a drum debarker (12 respondents or 67 percent) followed by a ring debarker (four respondents or 22 percent), and a peeler or a rotary debarker (one respondent or 11 percent each). One respondent (11 percent) uses a drum debarker for pulpwood and a ring debarker for sawtimber. Of the 12 respondents that use a drum debarker, 11 (92 percent) manufactured one or more pulp products. Respondents who reported using a ring debarker, a peeler and a rotary debarker were associated with solid wood product mills.

Burning within the manufacturing facility is the most common method for disposing of the residue generated during the debarking process (Table 8). Three mills both burn their waste bark in the mill and sell some of it to another facility.

Table 8. Number of responding mills by method of disposal of their debarked wood. Respondents could identify more than one method (n = 18).

Number of responding mills	Method of disposing of debarked wood	Product(s) represented	Number of respondents by product category	
			Pulp products	Solid wood products
12	Only burn it within the mill	Brown paper and lumber; cardboard (2 respondents); brown paper (3 respondents; fluff pulp (2 respondents); white and brown paper; brown paper and fluff pulp; pellets; lumber	10	2
2	Only sell it to another facility	OSB and siding; utility poles, cabin logs, pilings and posts	0	2
3	Both burn it within the mill and sell it to another facility	Brown paper and cardboard; OSB; lumber	1	2
1	Other – bark is sent to another facility which produces steam and electricity	White paper	1	0
0	Manufacture on-site one or more secondary products from the bark at your facility	None	0	0
0	Landfill it or pile/store it onsite	None	0	0

Other respondent comments – All respondents lumped together

Seven respondents (39 percent) provided open-ended comments about their use of fire-impacted bark and/or wood (Appendix 3). Of the two open-ended questions responded to by pulp product manufacturers, one indicated that fire-impacted timber is usually chipped in the woods and used for boiler fuel and the other that fires rarely occur in their area so there isn't a large volume of the material in the market to procure. Four of the five solid wood product open-ended comment respondents reiterated that fire-impacted wood is not a large problem for their mill because there is not a lot of fire-impacted timber in their procurement area. The fifth solid wood product respondent indicated that landscaping markets do not want charred bark as a secondary product so they need to find alternative markets for that waste material (which is why it is processed in batches separately from timber that is not fire-charred).

Comparison of responses from the Lake States and the southeastern US

Two-thirds of the responding mills are located in the southeastern US (Table 9). Focusing on some of the larger differences between the two regions, eleven of the twelve mills in the southeastern US manufacture a pulp product as compared to one of the six mills in the Lake States. Responding mills in the southeastern US place a heavier emphasis on purchasing pine species, are more likely to use a drum debarker, generally burn bark reside within the mill and assess for the presence of fire-impacted timber at multiple locations, and were more likely to note that fire-impacted wood had a negative effect on their process or end product.

Table 9. Comparison of responses to various survey questions for respondents in the Lake States and the southeastern US.

Factor	**Lake States**	**Southeastern US**
Number of responding mills	6	12
Species purchased		
Only deciduous species	2	0
Only coniferous species	3	8
Both deciduous and coniferous species	1	4
Does the mill manufacture a pulp product?	1	11
How does the mill debark the wood?		
Drum debarker	0	11
Ring debarker	3	0
Rosser head debarker	0	0
Flail debarker	0	0
Peeler debarker	1	0
Rotary debarker	1	0
Drum debarker (pulpwood) and a ring debarker (sawtimber)	0	1
How is bark disposed of after debarking?		
Manufacture on-site secondary products from the bark	0	0
Burn within the mill	1	11
Landfill or pile/store onsite	0	0
Sell to another facility	2	0
Both burn it within the mill and sell it to another facility	2	1
Convey to adjacent facility to produce steam	1	0

Where is the presence of fire-impacted bark or wood assessed?		
In the woods before timber is purchased	2	1
In the woods before timber is harvested	0	0
In the woods before timber if hauled to the mill	1	0
At the scale shack	0	2
In the woodyard	0	0
Both scale shack and woodyard	0	3
In the woods before timber is purchased and at the scale shack	1	2
In the woods before timber is hauled to the mill and in the woodyard	1	0
At all locations in the woods and at the scale shack	0	1
At all locations in the woods, at the scale shack and in the woodyard	1	1
In the woods before timber is purchased and harvested and at the scale shack	0	1
In the woods before timber is purchased and hauled to the mill and at the scale shack	0	1
How does the mill assess the presence of fire-impacted bark or wood?		
Visually	6	11
Scanners	0	0
Both visually and scanners	0	0
Both visually and with a probe	0	1
How does fire-impacted wood impact their process or end-product?		
Reduces product quality	2	6
Need to alter inputs to the process	0	1
Additional need to clean the material	1	1
No impact	1	1
No impact as long as wood fiber is not charred	1	0
No impact if it doesn't add black fleck to the product	0	1
Do not purchase	1	0
Reduces product quality for white paper (can't use it) and need to alter inputs to the process (add more bleach)	0	1
Additional need to clean material (so it doesn't show up in the brown paper) and causes a reduction in yield going through the digester	0	1
Does the mill purchase material where fire is restricted to bark?		
Yes	5	12
No	1	0
What happens to loads of fire-impacted bark received by the mill?		
Mixed in with all other loads received	4	12
Processed separately with other fire-impacted timber	1	0

Does the mill purchase material where fire impacted both bark and wood? Yes No	 1 5	 3 9
What happens to loads of fire-impacted bark and wood received by the mill? Mixed in with all other loads received Processed separately with other fire-impacted timber	 1 0	 3 0
Have mill specifications for the amount of fire-impacted wood changed over time? Yes No	 0 6	 0 12
Has the mill changed anything in its process to use more fire-impacted wood? Yes No	 1 5	 0 12

Conclusions

The authors recognize that the number of respondents who provided input into the mill survey results is relatively small (18 respondents). As such, the results are not definitive and would require additional sampling to be conclusive.

Despite the limited sampling, the results provide some insights on how fire affects the wood products industry, and the ability for mills to efficiently produce various types of wood products. The most important thing to the forest industry is availability of a reliable supply of quality timber, and producing their products in a cost-effective manner. When it comes to the utilization of fire-impacted timber, opportunities depend on regional context including the mills, the products manufactured, the procurement specialists, tree species, and timber conditions on the ground including (e.g. past fire severity, time since last fire). Respondents were consistent in reporting that fire-impacted timber affects the quality of pulpwood and pulp products. Those mills do not want fire-impacted timber in their product due to dark-colored imperfections, or flecks of char that taint the color quality of their product.

Dimensional lumber producing mills did not express concern regarding fire-charred bark; however, if the char damaged wood fibers, that char can degrade the structural integrity of the wood and result in weaker strength products. The use of a ring debarker, peeler or rotary debarker by solid wood product mills allow them to remove some or all of both the bark and fire-charred wood (Watson and Potter 2004). Those debarkers can be adjusted to more aggressively remove char. In addition, slabs removed from the outer ring of a log during a sawing process can remove additional charred material.

Bark charred-timber can affect the value and marketability of secondary products for some mills (e.g. mulch, animal bedding). Fire-impacted bark and wood in these situations can be burned at the mills for power generation.

Of the 18 mills surveyed, 17 will purchase fire-impacted timber and only one indicated they do not buy any fire-impacted timber, regardless of the amount of char, or the char depth. Of the 17 who will purchase fire-impacted timber, 16 said they do not sort the fire-charred timber separately from other non-burned material when it arrives at the mill. This helps simplify the processes of moving raw timber through the mill resulting in final products. Thirteen of the respondents who indicated they purchased fire-charred timber stated that they would only purchase the timber if the charring were restricted to the bark.

Specifications for the amount of fire-impacted bark and wood allowed within a load or log vary by the products made. A pole producing mill indicated that char is not a problem as long as the damaged fiber is limited to the bark and can be peeled off. Mills producing pellets stated the wood must be solid with little decay. Cardboard and white/brown paper mills reported less than 15%, and 5%, respectively, of the material in a load can be fire-impacted due to the effort needed to limit the dark colored material in the final product. If there is more of the charred material, more effort is needed to clean and wash that timber to ensure staining does not occur to an unacceptable level within the finished product.

While responding mills reported that their specifications for the amount of fire-impacted timber they purchase have not changed over time, one mill stated they have more flexibility in their mill operations and the amount of fire-impacted timber they can utilize when there is an increase in the availability of this timber (e.g. salvage logging post wildfire). The respondent indicated that they previously had used fire-impacted timber mostly for boiler fuel.

Opportunities for additional research

This study focused on answering questions about mill procurement of fire-impacted bark and wood within the Lake States and the southeastern US. As such, its scope was limited. The study has identified opportunities for additional research.

Additional sampling in the Lake States and the southeastern US could build more depth of understanding for the findings reported here. In addition, expanding the sampling to include the western portions of the United States and across Canada could help provide more insight into the impacts and utilization of fire-impacted timber across North America.

This study did not attempt to gather information about the impact of fire-impacted timber on either stumpage prices or the price of material delivered to a mill. To get fire-impacted timber utilized quickly to avoid loss of volume and value, landowners may need or be forced to reduce the stumpage price for that timber to incentivize buyers. For example, fire-killed timber to be salvaged within the 2021 Greenwood Fire in northeastern Minnesota was sold as pulpwood rather than sawtimber though the timber was of saw quality (14in+ DBH) prior to the wildfire (Keely Drange, personal communications, January 25, 2022) and utilized accordingly. Consuming mills may reduce their price paid for the material because it reduces product quality and/or requires additional effort to process, clean or bleach the timber.

Comparing timber sale revenue from wildfire-killed timber and timber impacted by prescribed fire is another area where further exploration is needed. It is expected that these fire scenarios offer very different realities for the post-fire condition of a stand. As opposed to having much fire-killed timber that needs to be utilized quickly, as might be the case in some wildfires, prescribed fires mostly keep canopy tree mortality to between zero and three percent and chars the lower bole of canopy trees. As such, quick-sale salvage logging would not be required following a prescribed fire. It is hypothesized that if a forester can plan to conduct the harvest 7-10 years following the lower-bole-charring prescribed fire that timber sale revenues would be no different than if prescribed fire had not been used. Thus, building several years into the planning cycle between a prescribed fire and a harvest of the timber is recommended.

Harvesting and processing fire-impacted timber could also affect harvesting operations. Sauder (1996, 1997) reported that only skidding costs were not increased when harvesting burned timber. Araki (2002) noted that extra maintenance might be required for harvesting equipment due to more frequent oil and air filter changes. Minnesota logging business owners expressed concern about reduced productivity and wood quality when they operated on salvage sales (Russell and Blinn, 2018).

Literature Review

Fire ecology

Fire is the result of a chemical reaction between oxygen in the air and some sort of fuel (e.g., gasoline, wood, leaf litter) when that fuel is heated to its combustion temperature. It plays a key role as an ecosystem process (Bond et al. 2005). It was directly and indirectly responsible for shaping ecosystems, plant reproduction and tolerance to fire long before the emergence and evolutionary development of Homo sapiens (Pausas and Keeley 2009). For example in trees, thicker bark in *Pinus* and *Quercus* evolved as a mechanism to survive in fire-prone landscapes (Stickel 1935, Hare 1965, Keeley and Zedler 1991, Pausas and Keeley 2009, Pausas 2014) and the serotiny of cones of certain pine species is tied to fire (Lamont et al. 1991).

Fire dependence is a trait in which particular species rely on fire to eliminate existing competition, even exhibiting a positive growth response to a fire, due to the freeing up of an abundance of nutrients and light availability to allow for regeneration (USDA 2006). Fire influences the availability of resources and facilitates succession in fire dependent systems. Conifer stands tend to have evolved alongside fire (Wright 2014). Fire facilitates regeneration for numerous pine species by altering existing conditions to something more favorable such as preparing a suitable seedbed and reducing competition (Wright 2014). The conditions change depending on the conditions that a particular species prefers (Wright 2014). In the case of jack pine (*Pinus banksiana)* and relatively low-frequency fire regimes, serotinous cones are produced and successively accumulate in the crown to prepare for high intensity crown fires which will open them up and disperse the seeds. High-frequency surface fire regimes, however, are beneficial in both jack pine and red pine (*P. resinosa)*-dominated plant communities through reducing competition in the understory and preparing the seedbed for pine regeneration.

Fire intensity dictates its impact on trees. In the case of a severe fire, there will be virtually no living trees or other vegetation remaining, which translates to a sudden increase in available light and the exposure of bare soil. Oak savannas are another fire-dependent ecosystem. Results from a Missouri study indicate that the presence of thicker bark for insulation and rapid compartmentalization due to the ability to produce tyloses in the white oak group grants these species a greater resistance to fire (Dey and Schweitzer 2018). Certain pines have adapted a similar tendency as oaks to produce thicker bark in order to insulate the vascular tissue and wood (Pausas 2014). Brose and Van Lear (1999) reported that the thin bark of American beech (*Fagus grandifolia*) and red maple (*Acer rubrum*) made the trees susceptible to considerable injury from a prescribed burn in an oak-dominated stand while thicker bark species withstood the fire with little to no damage. But, the presence of slash near residual crop trees contributed to and prolonged intense fire against those trees which resulted in 5 to 20 percent of the trees being killed or severely damaged (Brose and Van Lear 1999).

Ground, surface, and crown fires are three distinct varieties of forest fire ranging in severity and position in the forest strata (Pausas 2014). Ground fires burn below the leaf litter or hummocks and can result in a great loss of below ground organic matter (Albini 1984). Surface fires are characteristically limited to litter and above ground fuels present on the forest floor (Pausas 2014). They are considered to be stand maintenance fires in forested settings and help to create a natural variation in species composition across a landscape (Heinselman 1973). These fires are often used in forest management as prescribed burns because they are useful for thinning dense stands to reduce competition from species that are not fire adapted (Miller 2000). The last are crown fires which take place in the canopy. Crown fires are considered to be stand replacing fires as they initiate from surface fires and burn tree crowns killing the majority of overstory trees (Heinselman 1973, Keyes 2002, Pausas 2014).

The presence of ladder fuels which can carry a fire burning in low-growing vegetation to taller vegetation (e.g., from the forest floor into the tree canopy) increases the likelihood of a fire spreading into the crown or causing overstory mortality due to crown scorch from high heat release. Because of the high intensity of crown fires, they generally have a shorter duration because they consume all available fuel in a brief amount of time (Pausas 2014).

Fire suppression and management

After a number of catastrophic fires occurred in the US during the late 1800s and early 1900s (e.g., Peshtigo 1871, Hinckley 1894, Cloquet-Moose Lake 1918) (National Park Service), fire suppression became a concern to human safety and timber value. In fact, when the US Forest Service was established in 1905, fire suppression became the primary task of the organization across all forested areas it administered. The 1960s brought change to legislation implementing wildfire suppression when various studies reported that fire is a natural process that is key to maintaining health in some ecosystems (Pyne 2017). For example, forest types that normally experienced fires ultimately produced an excessive amount of leaf litter and woody debris that began to build up under fire suppression (Dey and Schweitzer 2018). Without fires to reduce that build-up of fuel, the potential for a catastrophic fire increased (Stone 2004).

Prescribed fire is a widely used management tool today in parts of the US. In 2017, 11.3 million acres were treated with prescribed fire in the US, the majority of which (80%) were burned to meet forestry objectives (Melvin 2018). Approximately two-thirds of those acres were in the Southeast.

While policies have changed today to encourage the use of fire as a management tool in some ecosystems through controlled burns, its use is often controversial due to factors such as compartmentalization which has resulted in smaller land holdings, increased number of built structures within the forest, concerns about smoke, and pressures to human health (van Wagtendonk, 2007). That reduction in use of fire as a management tool has caused some shifts of fire dependent species such as oak, hickory and pine to systems that are intolerant of fire (Penn State 2019). However, the use of fire as a silvicultural tool has increased in recent decades due to evidence of benefits to specific ecotypes (Brose 2014).

Concerns about use of fire as a management tool are rooted in shielding people from uncontrolled fires that once occurred over large expanses of land, like the large fires that occurred from about 1850 to 1950 (Pyne 2017, Dey and Schweitzer 2018). Harvesting practices used by European settlers such as leaving large amounts of slash (coarse and fine woody debris) on the ground following logging operations, clearing land for settlement, and high grading contributed to a perceived fire problem threatening human life and timber availability in the Lake States and elsewhere (Pyne 2017).

Effects of a fire injury to trees

Chambers (1986) reported that fire damage affects tree growth and survival both through direct and indirect effects. The direct effects cause cell or tissue death because of high internal temperatures. Crown consumption and crown scorch are the most visible signs of fire injury to pines, often affecting the subsequent growth and survival of the tree. Indirect effects reported by Chambers (1986) can occur through fire-caused changes in soil microorganisms, nutrient cycling or increased attractiveness and susceptibility of the trees to insects and disease.

Bowyer et al. (2007) provide a review of the impacts to wood as it is heated. Dey and Schweitzer (2018) summarize the types and determinants of fire injury and damage. While they indicate that fire can be compatible in oak timber management if it is used properly, they also note that it has the potential to damage trees and the forest if misapplied.

Scar closure following a fire is related to wood quality as it slows aerobic wood decay and removes a point of fungal entry (Rayner and Boddy 1988, Stambaugh et al. 2017). While additional burns which occur when fire scar wounds are open have the potential to enlarge basal cavities and cause further wounding, complete closure of a scar facilitates renewed production of clear, straight-grained wood.

Effects of a fire injury can have a wide variation of outcomes to trees individually and at a forest-wide scale depending on species and their characteristics. The effects can be broken down into two distinct categories: first-order and second-order effects (Bär 2019). First-order effects are a result of heat damage, and involve the tree's buds, foliage, vascular system, and roots (Bär

2019). Second-order effects occur after the fire and can be observed as restrictions in water and nutrient transport within the tree, photosynthesis, and susceptibility to pest or pathogen infestation (Bär 2019). Overall, timber quality may be impacted by both first- and second-order effects, but the key difference is that first-order effects are more immediate whereas second-order effects may take a longer period of time to occur. To withstand first- and second-order impacts of fire, some tree species have developed specific fire-resistant traits to give themselves advantages over their competition.

Species that adapted to having slower burning surface fires on the landscape are likely to have developed a thicker layer of bark to assist in survival and reproduction (Pausas 2014). When a fire occurs, the characteristic that is paramount to whether a tree survives or sustains an injury is bark thickness (Keeley and Zedler 1991, Pausas and Keeley 2009, Pausas 2014). The idea expressed by previous research is that the genetic trait of bark thickness varies, and individuals with favorable bark thickness conducive to insulating the stem are more likely to survive and successfully regenerate (Keeley and Zedler 1991, Pausas and Keeley 2009, Pausas 2014). In other words, a fire regime will select for individuals, over time, where bark is thick enough to survive a fire, but there is no incentive to produce bark that exceeds sufficient thickness (Pausas 2014). For example, red pine found in an area with routine surface fire would not have genes selected for thick bark extending up the entire bole of the tree (Pausas 2014). Instead, the most favored trait in this case would be thicker bark at the base of the stem, since the majority of the fire impact would be centered there (Keeley and Zedler 1991, Pausas 2014).

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Appendices

Appendix 1. Survey introductory script.
Appendix 2. Impact of fire on timber marketability survey.
Appendix 3. Listing of open-ended responses to survey question 21 -- Is there anything else about the use of fire-impacted bark and/or wood at your mill which I haven't asked you? If so, what else would you like me to know? (n = 7)

Appendix 1. Survey introductory script.

Hello, my name is Isaac Harberts. I am an undergraduate student in the Department of Forest Resources at the University of Minnesota. I am assisting three staff members explore the use of fire charred wood and bark in selected mills within the Lake States and Southeast US. The study seeks information about your mill as well as the use of fire-impacted bark and wood within your facility. Your mill was selected because it is a major purchaser of pine within our two study areas.

The survey should take about 20 minutes to complete. Your responses to all questions will be kept completely confidential. Only summaries of responses will be reported. No individual responses will be attributed to any company or individual.

Your participation in this survey is voluntary and you can withdraw at any point during the interview. You do not have to answer all questions. However, your input is important because it will influence future research and outreach.

Are you willing to participate? If so, do you have any questions before we begin?

Appendix 2. Impact of fire on timber marketability survey.

Understanding the Impact of Fire on Timber Marketability in the Lake States and Southeastern United States

Respondent demographics

1. What is your job title?
    - ○ Mill manager
    - ○ Head of procurement
    - ○ Procurement forester
    - ○ Other (please specify) _____________

2. How do you influence the mill's wood procurement process?

3. How do you influence the mill's manufacturing process?

Mill demographics

4. Where is your mill located?
    - ○ City _____________________________
    - ○ State _____________________________

5. What species does your mill purchase?
    - ○ Aspen
    - ○ Maple
    - ○ Basswood
    - ○ _______________ pine
    - ○ _______________ spruce
    - ○ _______________ fir
    - ○ Other (please specify) __________

6. What product(s) do you manufacture at your mill (this facility)?
    - ○ White paper
    - ○ Brown paper
    - ○ Cardboard
    - ○ Lumber
    - ○ Oriented strand board (OSB)
    - ○ Plywood
    - ○ Pellets
    - ○ Other (please specify) __________

7. Does your mill debark wood?
   - ○ Yes (Go to Question 8)
   - ○ No (Go to Question 10)

8. How does your mill debark the wood?
   - ○ Drum debarker
   - ○ Ring debarker
   - ○ Rosser head debarker
   - ○ Flail debarker
   - ○ Other (please specify) ______

9. What does your mill do with the bark after the debarking process?
   - ○ Manufacture on-site one or more secondary products from the bark at your facility (please specify product(s)) _______
   - ○ Burn it within the mill
   - ○ Landfill it or pile/store it onsite
   - ○ Sell it another facility
   - ○ Other (please specify) _______

Specifications about the amount of fire damaged wood allowed

The next several questions ask you to think about the material which your mill purchases and uses in making products.

10. Where does your mill assess for the presence of fire-impacted bark or wood?
    - ○ In the woods before timber is purchased
    - ○ In the woods before timber is harvested
    - ○ In the woods before timber is hauled to your mill
    - ○ At the scale shack
    - ○ In the woodyard
    - ○ Both scale shack and woodyard
    - ○ Other (please specify) _______

11. How does your mill assess for the presence of fire-impacted bark or wood?
    - ○ Visually
    - ○ Scanners
    - ○ Both visually and with scanners
    - ○ Other (please specify) _______

12. How does fire-impacted wood impact your process or end-product(s)?
    - ○ Reduces product quality (please specify) _______
    - ○ Need to alter inputs to your process (please specify) _______
    - ○ Additional need to clean the material (please specify) _______
    - ○ Other (please specify) _______

The next questions are about material where the fire impact is restricted to the bark and doesn't impact the wood.

13. Does your mill purchase material where the impact of fire is restricted to the bark?
    - ○ Yes (go to Question 14)
    - ○ No (go to Question 16)

14. What are your mill's specifications for the amount of fire-impacted bark allowed within a load of logs delivered to the mill?

15. Are loads with fire-impacted bark mixed in with all other loads received by your mill, or is it processed separately with other fire-impacted timber?
    - ○ Mixed in with all other loads received by the mill
    - ○ Processed separately with other fire-impacted timber
    - ○ Other (please specify) _______

The next questions are about material where the fire has impacted **both** the bark and wood.

16. Does your mill purchase material where fire has impacted **both** the bark and wood?
    - ○ Yes (go to Question 17)
    - ○ No (go to Question 19)

17. What are your mill's specifications for the amount of fire-impacted bark **and** wood allowed within a load of logs delivered to the mill?

18. Are loads with fire-impacted bark and wood mixed in with all other loads received by your mill, or is it processed separately with other fire-impacted timber?
    - ○ Mixed in with all other loads received by the mill
    - ○ Processed separately with other fire-impacted timber
    - ○ Other (please specify) _______

19. Have your mill's specifications on the amount of fire-impacted wood changed over time?
    - ○ Yes -- How/in what way? (please specify) _______
    - ○ No

20. Over time, has your mill changed anything in its process to utilize more fire damaged wood?
    - ○ Yes -- What have you done? (please specify) _______
    - ○ No

21. Is there anything else about the use of fire-impacted bark and/or wood at your mill which I haven't asked you? If so, what else would you like me to know?

Thank you very much for helping us with this important survey.

Appendix 3. Listing of open-ended responses to survey question 21: "Is there anything else about the use of fire-impacted bark and/or wood at your mill which I haven't asked you? If so, what else would you like me to know?" (n = 7)

- Cardboard -- Fire-impacted material is usually chipped in-woods and used for fuel.
- White paper -- There are limited fire issues within their procurement area so they do not have to deal with a large volume of charred wood on the market. They have occasionally discussed whether or not they should take impacted bark but it occurs so infrequently it is not an issue.
- OSB and siding -- Fires in [state] are generally small and they get put out quickly. Over his career (26 years) he has only addressed this situation twice. Paper companies will shy away from char because of the impact on the final product, sawmills can work through it. In their mill they remove the bark off with a ring debarker so it comes out fairly clean. Fire char (bark and/or wood) limits who will purchase it due to varying specifications.
- Utility poles, cabin logs, pilings, posts -- Always have used fire damaged wood.
- Pellets -- Fire-impacted wood has little to no effect on pellet quality or the manufacturing process.
- OSB -- They don't sell their by-products to paper companies and the char really only affects paper companies.
- Lumber -- Landscape markets don't want charred bark so they have to find alternative markets for those residuals. Supply chain is tight.