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Perceptions of and adaptation to changing winter weather by logging business owners in northern Minnesota, USA

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ABSTRACT

Focus groups with northern Minnesota logging business owners were held in spring 2023 to understand perceived and observed winter weather changes, challenges they may be facing due to any winter weather changes, and strategies they are taking to adapt to changing conditions. These discussions focused on logger perceptions of weather-related changes during the winter logging season over the course of their career, impacts of weather-related changes on harvest productivity, changes in business practices due to weather-related changes, and positive impacts due to winter weather changes. Most focus group participants are perceiving changing winter weather conditions and experiencing additional challenges to their winter logging operations due to these changes. They described how winter weather changes are impacting harvesting production and profitability, as well as how they have adapted their logging practices in response to these changes. The evolution of logging equipment and the characteristics of timber tracts available to harvest in winter, as well as greater sensitivity to soil rutting and compaction, make it difficult to discern the extent to which their observed changes in winter logging operations can be attributed solely to weather-related changes.

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Introduction

Approximately one-third of Minnesota is forested (Oswalt et al. 2019) with the most dense forest cover occurring in the Laurentian Mixed Forest Province in the northern part of the state (Minnesota 2021). That area is characterized by broad areas of conifer forest, mixed hardwood and conifer forests, and conifer bogs and swamps (Minnesota 2024a). The landscape ranges from rugged lake-dotted terrain with thin glacial deposits over bedrock, to hummocky or undulating plains with deep glacial drift, to large, flat and poorly drained peatlands. Wetlands are a common landscape feature within those forests (Phillips 1997). Aspen (*Populus tremuloides* Michx.), black spruce (*Picea mariana*) and northern and lowland hardwoods are the most common forest types (Minnesota 2021).

Timber harvesting in Minnesota

The forest industry is the fifth largest manufacturing sector in Minnesota by employment (Minnesota 2021) with most of the industry based in the northern part of the state. Annual harvest levels are approximately 5.85 million tonnes (Minnesota 2021) with about 53% of that volume harvested during the winter (Blinn and Nolle 2023). Winter harvesting is more common because the risk of soil compaction is reduced when soils are frozen (Kolka et al. 2012).

Stone (2002) reported that the greatest change in logging equipment during the previous 25 years within the northern Lake States was the increased use of mechanized harvesting equipment, especially the use of feller-bunchers and grapple skidders, with a decrease in the use of chainsaw felling and cable skidders. The increased level of mechanization was accompanied by increased logging productivity and greater size, weight, horsepower, and static ground pressure of the equipment with a greater potential to degrade soil properties through compaction and rutting (Stone 2002). Logging businesses have continued to become more mechanized over time (Bolstad 1980; Jaakko Pöyry Consulting, Inc 1992; Puettmann et al. 1998; Powers 2004; Blinn et al. 2014, 2019; Blinn and Nolle 2023). While the authors are unaware of any reported studies which have assessed how soil impacts have changed due to mechanization in Minnesota or regionally, Long-Term Site Productivity studies conducted in the Lake States 20 and 25 years post harvest have reported recovery of bulk density at the surface (0-10 cm) but not at deeper portions of the soil profile and that soil compaction effects were most pronounced in silt loam and sand (Slesak et al. 2017; Curzon et al. 2022).

Historical changes in northern Minnesota's winter weather

Winter weather in northern Minnesota has been changing. The Minnesota Pollution Control Agency reported that the state is getting warmer, especially on winter nights in the northern part of the state. Daily average minimum temperatures during winter (Dec-Feb) increased 4.1 degrees C from 1895 to 2021 (Minnesota 2023). Minnesota lakes have lost an average of 10

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to 14 days of ice cover in the past 50 years. The Minnesota Department of Natural Resources reported that average daily winter low temperatures in northern Minnesota rose more than 15 times faster than average daily summer high temperatures and that the frequency of −37° C readings have fallen by up to 90% since 1970 (Minnesota 2024b).

With its high albedo and low thermal conductivity, a snowpack acts as an insulating layer over the soil surface, influencing both soil temperature and frost depth (Zhang 2005; Campbell et al. 2010) and thus soil strength. As compared to a thin snowpack, a thick snowpack results in warmer soils and decreased depth of soil frost (Hart and Lull 1963; Groffman et al. 2001; Hardy et al. 2001; Decker et al. 2003; Bardou and Delaloye 2004; Friesen et al. 2021; Stockstad et al. 2022) which can negatively affect winter logging.

Given the importance of the logging industry, this research was intended to document impacts of changing winter weather conditions on logging operations and productivity in northern Minnesota, US.

Background

While research has been undertaken to model how climate change might influence logging costs or operations (e.g. Kuloglu et al. 2019; Chugunkova and Pyzhev 2020; Kologlu et al. 2021) or to document how changing winter conditions have altered harvesting trends (e.g. Rittenhouse and Rissman 2015), little research has directly queried loggers about their perceptions or adaptations to changing winter weather conditions. Geisler et al. (2016) queried loggers about their perceptions of seasonal environmental changes in their operations. While not focused specifically on perceptions of winter weather changes, some winter weather-related issues were identified in their study. Loggers in their study cited concerns and perceptions about shorter winters, extreme cold and lack of frozen ground in their operations. Specifically, some of the study participants indicated they had experienced shorter logging seasons in recent winters and an earlier timing of snowfalls prior to frozen ground conditions. In another study, Rittenhouse and Rissman (2015) used historic climate data and harvesting records to analyze how changes in the winter weather conditions have impacted timber harvesting patterns on public lands in Wisconsin. A reduction in frozen ground conditions of 2–3 weeks over the period 1948–2012 was documented as well as a shift to greater harvesting of species found on sandy soils in winters with shorter frozen ground periods. Similarly, Lehtonen et al. (2019) modeled the impact of a changing climate on soil frost conditions to examine how the loss of frost depth and duration can impact winter logging equipment in Finland.

Blinn and Nolle (2023) conducted a recent survey of Minnesota logging business owners, which included the question, "Have recent weather patterns impacted your logging operations?" In response to this question, 53% indicated "Yes," 41% indicated "No" and 6% reported that they "Didn't know." Given that more than half of the respondents to this survey indicated weather patterns have impacted their operations and the dearth of literature in this topic area, the goal of our study was to query logging business owners in Minnesota about their perceptions and observations of winter weather changes, challenges they may be facing because of winter weather, and strategies they are taking to adapt to changing conditions.

Materials and methods

Focus groups

Data were collected through focus groups with Minnesota logging business owners. Focus group questions were developed by the entire study team. After several rounds of question drafting and subsequent discussion, the study team finalized a list of questions that centered around the logger's perceptions of weather-related changes during the winter logging season over the course of their career, impacts of weather-related changes on harvest productivity, changes in business practices due to weather-related changes and positive impacts due to winter weather changes. Additionally, a short questionnaire was developed by the study group to gather background data on the focus group participants administered at the end of the focus groups. The University of Minnesota's Institutional Review Board reviewed the protocol for the project and determined it was exempt from further review.

Focus group participant recruitment was based on a list of Minnesota logging business owners (loggers who were members of the Minnesota Logger Education Program's (MLEP) and had registered for their 2023 spring conferences. Criteria used when identifying potential participants included years of membership in MLEP and annual levels of production. We segregated focus group participants according to annual production, as we thought loggers would feel more comfortable discussing the questions we posed with other loggers of similar types and businesses, number of employees, and logging equipment configurations. We also wanted to see whether specific comments were dominated by large or small volume logging businesses. With assistance from the MLEP executive director, we identified small and large volume producers using 20,900 tonnes/year annual production as the breakpoint for defining these two cohorts. Blinn and Nolle (2023) reported the average annual production of a Minnesota logging business was 21,452 tonnes in 2021.

Forty-six logging business owners were invited to participate in one of the six focus groups based on which spring logging conference they were registered to attend. Invitations were extended to an equal number of small and large producers. MLEP offered continuing education credits as an incentive for invitees to participate in a focus group. Thirty-six loggers participated in six focus groups, which were conducted in March and April 2023, three each at the annual MLEP Spring Conferences held in Virginia, Minnesota and Bemidji, Minnesota. Two of the three Virginia focus groups were owners of small logging operations and two of the three Bemidji focus groups were large business owners. The number of focus group participants in a focus group ranged from four to nine, with an average of six loggers per focus group.

Each focus group lasted approximately 40–50 minutes. With permission of the focus group attendees, each focus group was audio recorded using Zoom. At the beginning of each focus group, participants were given written copies of the focus group questions (Table 1). Additionally, participants were asked to complete a short questionnaire that gathered

Table 1. Focus group questions.

1. Over the many years that you have been in the logging business, have you observed weather-related changes during the winter logging season? If so, describe what changes you've observed.
2. Have these weather-related changes impacted your logging business' ability to harvest timber sales during the winter logging season? If so, describe what impacts you've experienced.
3. Have winter-related changes impacted the productivity of your logging operations? If so, in what way?
4. In response to these weather-related changes and impacts, describe what changes you've made to your logging operations during the winter logging season (e.g. tree species, equipment, staffing, type of timber sales purchased).
5. Have any weather-related changes had a positive impact on how you conduct winter timber harvesting activities? If so, describe these beneficial impacts.
6. As you look into the future, do you expect weather-related changes to have less/greater/no change in impact to your winter logging operations? Why do you think this and how do you think future weather changes may impact your logging business?
7. Have winter weather-related changes impacted your logging business beyond just the frozen ground logging season (e.g. throughout the year)? If so, describe these impacts and any changes you've made in your logging operations to address these impacts.
8. Are there any other comments or observations you'd like to share regarding how weather-related changes have or may impact your winter logging operations?

Table 2. Descriptive information for the focus group participants.

Focus Group Production Size*	Summary Statistic	Years Logging Experience	Annual Production (tonnes)	Winter Harvest Volume (%)	Winter Crews (n)	In-woods Winter E Employees (n)	Percent of Annual Harvest		
							Aspen	Other Hardwoods	Softwood
Large ($n = 21$)	Mean	39	62,230	61	2	7	57	22	21
	Maximum	56	418,000	80	6	24	80	70	60
	Minimum	15	2,090	50	1	1	30	10	0
	Count	21	20	19	14	16	21	21	21
Small ($n = 15$)	Mean	29	12,525	73	2	3	63	21	16
	Maximum	49	41,800	100	8	8	95	40	60
	Minimum	8	1,045	50	0	0	15	5	0
	Count	15	14	15	12	9	14	14	14
vvvv Overall ($n = 36$)	Mean	35	41,762	66	2	5	59	22	19
	Maximum	56	418,000	100	8	24	95	70	60
	Minimum	8	1,045	50	0	0	15	5	0
	Count	36	34	34	26	25	35	35	35

*Large = Large annual production (≥20,900 tonnes/year); Small = Small annual production (<20,900 tonnes/year).

background information about them and their logging business. Descriptive information from this survey about the focus group participants is contained in Table 2.

Qualitative data analysis

The audio-recorded focus groups were automatically transcribed via Zoom. The same researcher led each of the six focus groups, while the other two researchers observed some or all of the focus groups. The data were inductively analyzed using open coding to identify and analyze patterns in qualitative data consistent with thematic analysis procedures (Holton 1973; Braun and Clarke 2006). We followed the focus group convention of treating the unit of analysis as the group rather than the individual (e.g. Morgan 1997). Therefore, we were not able to attribute comments made during the focus group meetings back to an individual. The study team used an iterative process to identify and refine emergent codes, themes and sub-themes in the data. In the first step, all three researchers read the transcript and/or listened to the recording of one of the focus groups and individually identified codes and themes. After a discussion among the study team, a consensus set of themes emerged. In the second coding phase, each of the researchers listened to/read the transcript from one additional focus group using the consensus set of themes to determine whether coverage of all of the major concepts was captured by the current set of themes. Sub-themes were also developed in this coding phase. In a second study team discussion, themes and sub-themes were discussed and refined. All researchers reviewed the remaining four focus groups with the consensus themes and sub-themes to determine whether any additional themes or sub-themes were needed. In a final coding step, one of the researchers analyzed the full set of focus groups with the themes and sub-themes, resulting in some final refinements.

Results

Four distinct themes and several sub-themes emerged from the data. A description of each, including representative quotes from participants, is reported below.

Theme 1: perceived winter weather changes

Temperature changes

Focus group participants shared a range of observations and perceptions about changes in winter weather conditions from the time they started logging. Regarding winter air temperature, their comments highlighted three major ideas. The first was that winter air temperature seems milder now to them than when they first started logging. Second, the onset of the

very cold temperatures needed to freeze the soil seemed to be occurring later than in the past. For example, several noted that in the earlier years, the ground became frozen right after the November deer hunting season, whereas today it sometimes takes until January before the temperature is cold enough to freeze the soil such that they could commence winter logging operations. "W*inter starts later than in the past . . . winter logging used to begin just after deer season*." The last major idea was that extended periods of very cold temperature do not seem to last as long as they used to. As one logger put it, "*Cold spells don't last as many days as in the past; there just aren't as many consecutive days of way below zero temperatures*."

Precipitation changes

Loggers commented about changes they have observed in winter precipitation. Several noted that the amount of snow each winter seems to be less than in the past. One logger stated: '*Winters are drier today than in the past.*" Additionally, many made remarks regarding the timing of the onset of very cold temperatures and the first large snow event, which impacts the timing and depth of frost. As stated by one logger, '*We used to get cold weather before the snow, but now it's just the opposite. We now get snow before we get cold weather*.' Another summed it up this way, '*We've had warm winters in the past, but the early snow we now get is what's different.'* Others commented on the amount of winter rain. One logger said: *More rain is now occurring in the winter logging season than in the past . . . bad for logging because it pulls frost out of the ground. Can't drive on top of rain like you can snow."*

No perceived changes

While comments about observed changes in the winter air temperature and precipitation over time were numerous, some participants also stated they have not observed changes or trends in winter weather patterns over time. Among these comments, two sub-themes emerged. The first was the general lack of observed changes in the winter weather. Comments supporting this sentiment include, "*The start of winter is the same as it was years ago*.," "*Every year is different, sometimes it starts on time, sometimes earlier, sometimes later*." and "*Weather is random*." The second idea was a more nuanced observation about the lack of long-term trends in the winter weather. Several loggers suggested that while there have been short-term periods of above or below average winter temperatures and precipitation, they did not see any long-term patterns. Comments supporting this perception included, "*For a few years, it seemed we were starting later and ending earlier, but then we had a few years where it was just the opposite*." and "*Patterns are cyclical . . . no long-term trend . . . we're just paying more attention to weather today*." Finally, a few focus group participants offered their perspective on the idea of climate change in general. One logger summed up his belief about climate change this way, "*Climate change . . . BS . . . we had glaciers years ago . . . climate is always changing*."

Theme 2: impacts of weather changes on winter logging operations

Adverse impacts

Winter logging season. Several loggers remarked about how changes in winter weather conditions have impacted the winter logging season and their operations. A view offered by several focus group participants related to the length of the winter logging season. They remarked there are fewer operable days when the soil is frozen than in the past, with the shortened season due to the delay of the beginning of winter logging operations as opposed to the end when the spring thaw occurs. As expressed by one focus group participant, "*The start of the winter logging season is later, but the end of the winter logging season seems about the same to me*."

In spite of these sentiments regarding how changing weather conditions have impacted the winter logging season, several loggers attributed the reduction in the number of operable winter logging days to changes in logging equipment and not weather. Specifically, they noted that today's logging equipment is much heavier and requires greater frost depth to operate than the older equipment that is considerably lighter. "*Equipment changes impact your winter logging season; equipment is heavier today, which means we need to wait longer to get into the woods because more solid ground is needed*." and "*Yes, we're moving into the woods later, but equipment is bigger, so we have to have more solid conditions before we can move into the woods*." One participant attributed timber sale site characteristics as having the greatest impact on when winter logging can begin. "*The start of winter logging depends more on the type of sale than the weather conditions*."

Winter logging infrastructure. The effect of changing winter weather conditions on building and maintaining logging infrastructure was discussed by loggers. A common sentiment expressed was that loggers are spending more time and effort to freeze roads. Several felt that the increased frequency of having a large snow event before the ground is frozen requires them to spend considerably more time packing down and/or removing snow from their winter access roads in order to get them sufficiently frozen, which equates to greater operating expenses and reduced productivity. As one logger put it, "*The lack of extended cold periods, along with new snow, makes it very difficult to freeze up roads and the harvest site*." Another stated, "*Late freeze up makes it more difficult if we get an early heavy snow . . . the ground will never freeze up*." While this sentiment was common, a few loggers had a different take on the time spent on winter road development, as represented by one logger's observation that there was "*no consistent pattern*."

Milder winters are also changing the frequency with which certain types of logging infrastructure is used. For example, some loggers stated they are not able to build as many ice bridges to cross streams as they used to, due to the lack of

extended periods of extremely cold temperature. Others noted a greater use of slash mats to cross low areas. "*Using a lot more tops to drive my equipment on than in the past . . . helps keep ground impacts to a minimum.*" And "*Using mats that allow me to access some sites that I couldn't otherwise get into.*"

Also related to winter road-building issues, it was the perception among some loggers that timber sales are less accessible today than they were in the past, often resulting in more time spent building and keeping free from snow a winter road to access the tract. One logger described the impact this way, "*Sales are further back than in the past; we have to cross more swamps; that means spending more time and money to build and keep the roads frozen.*" Another commented, "*Sometimes, we spend a lot of time building a road into a sale that can't be accessed during the winter because of a lot of snow or thawing conditions.*"

Winter logging productivity. Focus group participants identified a range of impacts changing weather conditions have had on the productivity of their winter logging operations. The additional time spent to get their winter roads and other infrastructure to freeze was thought to be a major contributor to the decreased productivity of their winter logging operation. "*Winter volume productivity is not as high today due to more time packing down sales, clearing roads, and harvesting to be able to get the wood out when ground is less than ideal.*" and "*Wet ground operations mean we're less productive . . . spending more time freezing lowland crossings and getting a stable skid surface.*" Others cited the need to lay down slash in areas where the ground is not completely frozen, which takes additional time and adversely impacts productivity. On this point, one logger said: "*Laying slash to drive over decreases productivity with a conventional system . . . takes additional time.*" One logger indicated deep snow conditions can have a substantial impact on the productivity of his winter logging operation, stating, "*Making smaller drags with skidder in deep snow . . . too much weight makes it hard to operate . . . it takes more trips and more fuel to skid the same volume.*"

Beneficial impacts

While the conversation at all six focus group meetings focused on many of the challenges changing weather conditions were having on winter logging operations, several participants described how warmer winters are having a beneficial effect on their logging business. One beneficial effect mentioned by many was how the more moderate winter temperature was not as hard on their logging equipment. One logger stated it this way, "*It's easier on equipment . . . less wear and tear . . . easier to maintain equipment.*" Others mentioned that moderate winters saved them money on costly weather-related equipment repairs and downtime. "*Not as many broken pieces as in the past.*," "*Warmer winters means less equipment breakdowns.*" and "*Fewer down days today than in the past due to really cold temperatures.*"

A few loggers described how milder winters positively impacted their logging productivity. For example, having more rain in the winter rather than snow was seen as sometimes beneficial, as evidenced by this quote: "*Big rains in some areas help freeze the ground.*" Other positive outcomes associated with warmer winters were related to efficiency in operations, such as "*Felled wood doesn't freeze to the ground like it did in the past.*," "*Sometimes deep snow helps when the ground is soft . . . deep snow is not always a bad thing.*," and "*Pine harvest operations are more efficient today in winter, they limb better, everything seems faster . . . this offsets extra time needed in winter to prepare sites.*"

Several loggers also noted that warmer temperatures reduced their fuel costs in two ways. First, they were consuming less of the more costly number one diesel fuel, which is needed in very cold conditions because of its lower gelling temperature. "*Buying less #1 fuel today than in the past because the weather is warmer . . . less expensive.*' Second, logging machinery consumes less fuel per hour in warmer temperatures, as was expressed by this logger, "*The machines burn less fuel when the temperature isn't so cold.*"

Theme 3: logger adaptations to changing winter weather conditions

Equipment purchases

Focus group participants identified a range of modifications they have made to their logging equipment to adapt to changing winter weather conditions. The most commonly mentioned was the use of different tires and tracks (e.g. wider tires, dual tires, and tracks) on current equipment to reduce ground pressure which may enable them to operate for a longer period when the ground is not completely frozen. Several factors were cited as supporting rationale for switching to a wider tire configuration, one of which was reduced ground rutting. On the topic of rutting, one logger said: *Adding tracks allows you to go almost anywhere . . . in areas rubber tires can't go . . . which means less rutting.* Another said, "*I bought wider tires to keep me from rutting.*" A second benefit of different tire configurations that was discussed was increased access. One logger said: "*Adding tracks allows me to get around in more places in the winter.*" while another said, "*Dual tires decrease compaction and allow me to operate in areas I wouldn't be able to go into.*" Although most of the comments about switching to different tire configurations focused on the positive impacts, some negative impacts were also raised related to the purchase price and higher fuel consumption when using wider tires. One logger said,"*The cost of wider tires is high . . . plus it takes more fuel to operate.*"

Changing their tire and track configurations also afforded loggers some operating efficiencies associated with seasonal timing of their operations and the amount of work needed to prepare skid trails. On impacts to seasonal timing of logging operations, supporting statements included: "*Dual tires allow me to get into winter sales earlier than I otherwise could*," and "*Wider tires allow for more operating days in winter.*" Finally, operational efficiencies associated with less time to compact snow to freeze soils were attributed to wider tire configurations: *I can pack down trails and roads more efficiently . . . it takes fewer passes to get the road ready for use.*'

Aside from tire or track changes to existing equipment, some loggers described acquiring new equipment such as larger bulldozers, graders and different types of processors and forwarders/skidders. Some of the new equipment purchases were motivated by changing winter weather conditions. For example, one logger said, "*Moving to CTL (cut-to-length) because it gives more options to operate in areas conventional equipment can't go due to soft ground*," while another logger said: "*Using my feller buncher less in swamp conditions . . . it restricts where I can go without creating ruts*."

Other loggers were using different equipment to gain winter operating efficiencies that may not be directly in response to perceptions or reality of changing winter weather conditions. For example, one logger said: "*Nowadays, a grader is needed to open up winter roads . . . it's a must-have piece of equipment in winter logging*." while another said "*I bought a grapple skidder for winter skidding . . . it's more efficient than a cable skidder.*." Bigger, wider earth-moving equipment offers operating efficiencies and fuel and time savings when developing and maintaining winter logging access roads. A comment in support of this idea was: "*I purchased a wider dozer . . . it requires a fewer number of passes to build a winter road*." Some loggers indicated they prefer using older logging equipment because its lighter weight gave them more opportunities to operate in less-than-ideal winter logging ground conditions. As one logger put it, "*Big skidders had to stay out when the ground was soft because they were so heavy . . . I use the lighter, older equipment*." Yet, a few loggers expressed concerns about the ability to acquire older and lighter logging equipment. "*I can't find older equipment that is lighter than today's equipment*." and "*I'm interested in buying older equipment that's lighter, but getting parts to rebuild them can be difficult to find*."

Timber sale portfolio changes

Focus group participants commented about how changing winter weather had impacted the portfolio of timber sales they harvest in the winter. This conversation highlighted three themes. First, several stated they were being more selective about the types of timber tracts they were purchasing, with a preference for those that could be harvested year-round if winter ground conditions restrict access or purchasing tracts with closer access to existing roads. Examples of this sentiment included, "*I'm buying more summer wood to cut in the winter.*," "*Long distance access across low ground is riskier today because you may spend a lot of money getting the road in, only not to be able to cut the stand because the road can't get frozen*." and "*I don't bid on sales that are far back from the road in the winter . . . too expensive to build the road*."

Second, some loggers indicated they are holding a larger number of timber sale permits during the winter logging season than they have in the past to ensure they are able to keep their logging crews working. Comments along this line include, "*Need to have more sale options in case you can't operate a sale*," "*Holding more timber sales now than in the past. . .the investment is too large to risk running out of wood to harvest.*." A third theme regarding their winter timber sale portfolio focused on the need to better align the characteristics of the tracts they purchase with their logging equipment. Specifically, several noted the uncertainty regarding winter soil conditions were forcing them to target tracts where the probability of being able to harvest the stand was the greatest, as described by the following statements. "*The biggest issue is matching the type of timber sale permits purchased with the type of logging equipment I have.*," "*I'm more selective on the types of winter tracts I buy . . . need to make sure they will work well with my equipment*." and "*My older equipment breaks down more often, but I need to pick the sales that work well with this older equipment*."

Planning winter logging operations

Several loggers indicated more time is needed to plan their winter-logging season than was required in the past. These comments included, "*I spend more time planning and setting up winter sales . . . planning starts in the summer.*" and "*More time planning now to minimize down time*." A few indicated their additional planning consists primarily of, "*Spending more time watching weather forecasts in the winter*." A few focus group participants emphasized the need to be more entrepreneurial and flexible in approaching the winter logging season. Examples include, "*I look for market niches and other unique services or value I can provide to the private landowner.*," "*Have to be more creative today about how to manage winter sales*." and "*Loggers just adjust to changing weather conditions . . . learn and adapt*." One participant talked about the need to be ready to work when the winter logging conditions turn favorable, stating "*Sometimes you have to start at three in the morning . . . it makes a difference*." Others described their strategy to changing winter logging conditions as simply, "*Need to be creative*" and "*Take it day by day*."

Theme 4: external impacts on winter logging

Regulatory and administrative impacts

Many loggers talked about how regulatory and administrative provisions of timber sales exacerbate the impacts changing weather conditions have on their winter logging operations. Specifically, they felt public agency foresters are more inclined today to shut down a winter timber sale due to concerns over soil compaction and rutting than in the past. Examples of these comments included, "*DNR won't let you have winter sales as much as they used to if conditions get questionable*." and "*Have been kicked out of winter sales in the last two years . . . unheard of 20 years ago*." Several attributed this increased scrutiny to foresters who were relatively new to the profession. "*Foresters are more picky today on rutting . . . will shut you down sooner . . . younger foresters are more likely to be this way*." and "*Young foresters don't have the experience and business perspective . . . they're more willing to shut down a sale*."

Other focus group participants described their observations about how the characteristics of public agency timber tracts have affected their winter logging operations. Their comments included, "*Sales are smaller, so we need to move from sale to sale more frequently today.*," "*Sales include more regulations that limit access and operating conditions today than in the past*." and "*Agencies are less likely to allow us to cross wetlands today*." Several also remarked how the road distance required to access public timber sales in the winter is greater today than it was in the past. They commented these types of sales can be problematic, as they require additional cost to open and maintain the

access roads and impose additional risk that the ground does not stay frozen long enough to complete the harvest. "*There's plenty of winter wood, but accessing today is challenging . . . that's what's changed.*"

The evolution of logging equipment

The evolution of logging equipment and its impact on winter logging was a major topic of discussion during the focus group meetings. Several loggers attributed the reduction in the number of operable winter logging days to changes in logging equipment and not weather. They noted that today's logging equipment is much heavier and requires greater frost depth to operate than the older equipment that is considerably lighter. "*Equipment changes impact your winter logging season; equipment is heavier today, which means we need to wait longer to get into the woods because more solid ground is needed.*" and "*Yes, we're moving into the woods later, but equipment is bigger, so we have to have more solid conditions before we can move into the woods.*" One participant attributed timber sale site characteristics as having the greatest impact on when winter logging can begin. "*The start of winter logging depends more on the type of sale than the weather conditions.*" A few stated the larger equipment is more limiting when winter ground conditions are less than ideal.

Yet comments regarding the beneficial aspects of modern logging equipment in winter logging were much more numerous. In general, loggers indicated today's machines are more reliable, technologically advanced, and can fall and process trees faster than the older logging equipment. Comments were made related to temperature impacts to logging equipment, with one logger stating: "*Equipment today can be started at any temperature . . . don't need heaters or warmers like what was needed with the older equipment.*" Loggers also commented on the enhanced efficiency that modern logging equipment brings related to operating time and expense stating that "*GPS is used today to find felled trees that have been covered with snow. It tells you the location, species, and volume.*" and "*Today's equipment doesn't need as many drags . . . they can handle more wood per load.*"

Workforce availability

Another external factor that was discussed focused on workforce availability and challenges finding employees. While workforce availability is not a factor caused by changing winter weather conditions, its impact seems to be exacerbated by it. To take advantage of winter operating conditions, some firms may add employees to help them be more productive. For example, one focus group participant said "*Workforce availability makes it impossible to run 24 hours a day during waning days of logging season.*"

Discussion

The focus group discussions highlighted several differences between small and large volume logging operations. Because the number of large and small producer focus groups was not equal at each location, we were unable to make any comparisons based on venue. Small volume operators emphasized the need to be more entrepreneurial and innovative in response to changing winter logging conditions, much more so than the large volume focus group participants. Additionally, comments about being more attuned to watching weather forecasts in winter were only mentioned by small volume loggers. Large volume loggers, in contrast, dominated their sessions talking about changes in logging equipment weight and technology and their impact on winter logging operations. They also offered the majority of comments regarding workforce availability and the need to keep their equipment running without interruption during the winter. Large volume operators talked more frequently about the positive benefits of changing winter weather conditions, including fewer impacts on logging productivity and their equipment, than small volume operators. Comments about not perceiving any winter weather changes over time were also dominated by large volume logging businesses, perhaps due to non-weather related impacts to their operations (e.g. heavier equipment, greater regulatory control by forest managers).

As indicated in Table 2, several other logging business characteristics are associated with annual production. Smaller volume businesses harvested, on average, a greater proportion of their annual volume during the winter logging season than larger volume logging businesses (73% and 61%, respectively). Additionally, smaller volume operator focus group participants had been in the logging business 10 years less than the large volume operators, on average. Consequently, the differences between small and large volume-logging operators described above also extend to their dependence on harvesting wood during winter and additional time in the logging business. For example, the frequency of comments about the positive benefits of changing winter weather conditions was greater, in general, among those focus group participants who had been in business longer and where a lower portion of their annual wood production was during winter. Future research could explore how these and other business characteristics are related to perceptions of and adaptations to winter weather impacts on logging operations.

The logging industry is inherently sensitive to and influenced by weather conditions. Focus group participants confirmed this through statements such as: "*when you work outdoors, whether it is dirt construction, logging or farming, weather dictates everything,*" and "*I watch the weather all of the time.*" Similar to what was reported in Blinn and Nolle (2023), our focus groups highlighted that many northern Minnesota logging business owners are perceiving changing winter weather conditions related to temperatures and precipitation amount, type and timing. These changes, for the most part, are resulting in additional challenges to their winter logging operations. Reduced and/or inconsistent periods of frozen ground are creating difficulties for loggers to access harvest sites, as well as additional time and cost to freeze down access roads and infrastructure within the harvest site. These findings are similar to what were reported in Geisler et al. (2016) in the Upper Midwest, USA and Kellomäki et al. (2010) who reported reduced frost duration and depth in Finland.

Focus group participants talked about the impact winter weather changes are having on their production and profitability during the winter logging season. Many report having to

spend more time creating and freezing down roads when ground conditions are not optimal for winter logging (i.e. not frozen), which reduces the amount of time they can spend getting trees harvested and increases fuel costs to build roads. Additional costs are incurred when loggers have to move equipment out of harvest sites when ground conditions deteriorate. Loggers also talked about fewer operating days when the length of the season is contracted. All of these factors, attributable to a shorter or less consistent winter logging season brought about by changing winter weather conditions, impact the profitability of winter logging businesses. One logger said: *"It seems like we're working harder to stay afloat"*. In spite of the impacts of changing winter weather conditions on their business operations acknowledged by many of the loggers, no one expressed concern that winter weather conditions and/or other external pressures were driving them out of business. They pointed to many of the ways in which they are coping, adapting and innovating. Future research might explore how logging businesses have adapted in response to perceived changes in weather, and whether these changes have proven to be beneficial and reflected in the business's growth.

In response to winter weather changes and other pressures, focus group participants described a variety of adaptation practices they have undertaken. They described equipment changes that help them operate when ground conditions are not optimal (e.g. dual tires, tracks, switching to cut-to-length systems, relying on older, smaller equipment), but they also talked about some of the challenges they face with using the larger, heavier logging equipment that is the norm in the logging industry today when winter ground conditions are not optimal. They spoke of innovations in their logging operations they are making to allow them to adapt when ground conditions are challenging such as using spruce tops, stumps, and mats to cross marginally frozen or unfrozen ground. Some of the loggers described changing their procurement practices to include a mix of upland sales, easy access sales and/or summer sales to give them a fallback if they cannot complete cuts in lowground areas due to inoperable ground conditions. Many of the loggers talked about efforts to prepare roads and landings ahead of time, as well as being prepared to work in the woods when the conditions present themselves. Equipment and technology modifications such as adaptation strategies to climate and weather changes have been reported in other forestry and agriculture business sectors (e.g. Smithers and Blay-Palmer 2001), as have changes in the timing of operations and business practices to sync up with weather and climate conditions (e.g. Snyder et al. 2019). Future research might examine whether these equipment and logging modifications were made exclusively in response to a business' perceived changes in winter logging conditions.

Aside from winter weather conditions, loggers cited other external factors that are impacting Minnesota logging productivity, such as workforce availability and their perception that timber tracts are smaller and public agencies exert greater regulatory control over their logging operations. Results of our focus groups suggest an intersection exists between many of these external factors and changing winter weather conditions that creates a compounding effect on logging business operations. For example, the need to meet emission regulations, increased customer expectations for equipment which is reliable and durable, and consolidation within the global forest equipment industry during the past 20 years has resulted in an increased need and demand for larger equipment with a reduction in the number of machines and lighter-weight models being manufactured (R. Lawler, personal communication, 2 November 2023). While the use of larger equipment has many business advantages, loggers in our focus groups reported greater difficulties at times in using heavier equipment when winter ground conditions are not suitable. They identified a tension between this industry trend toward larger equipment versus the greater ability of older, lighter, smaller equipment to be able to be used in warmer winters when ground conditions are not optimal for winter logging.

Not all focus group participants felt that winter weather changes, even if they are occurring, are having a large impact on their winter logger operations. One reason for this perspective is that some stated that winter weather does not have as much impact on logging operations in upland areas where soils are commonly better drained. This suggests that winter weather changes will have differential impacts on loggers and the logging industry depending upon the species being harvested and the soils where those operations occur. Logging businesses that exclusively or primarily work in poorly drained lowland sites or peat soils may face more challenges to their operations under warmer winter conditions than those that work in uplands or have a more diverse portfolio of timber tracts and their associated site conditions.

When considering the impact that changing weather may have had on winter operations for loggers in northern Minnesota over time, it is difficult to separate weather-related impacts from the myriad other things that have changed over time. Logging equipment has tended to become bigger, stronger and faster, all of which have increased the size and weight of machines. For example, a reduction in the global forest equipment manufacturing industry has resulted in remaining models which are typically built to operate in the worst applications they might be used in, logger expectations on reliability and durability which has caused manufacturers to enhance the drivetrain components and steel structure, technology added to meet emission standards which required increasing machine size to accommodate the added components and customer expectations for increased productivity, which has resulted in booms and grapples needing to operate faster which meant that they also had to be stronger with a higher hydraulic flow ((bigger pumps, valves, hoses) (R. Lawler, personal communication, 2 November 2023). While equipment is larger and heavier today, manufacturers still try to work within ground pressure metrics and have increased the tire or track size to maintain similar ground pressure metrics compared to older machines (R. Lawler, personal communication, 2 November 2023). Research suggests there are other factors beyond machinery weight that impact soil compaction and rutting (Nazari et al. 2021).

In addition to logging equipment becoming bigger, stronger and faster, other non-weather related factors may be impacting the harvesting window. There is increasing awareness of the potential impacts to soil from harvesting operations (e.g. Grigal 2000; Cambi et al. 2014; Solgi et al. 2023) which has resulted in

harvesting operations temporarily shutting down to avoid soil damage. With an eye toward reducing soil impacts, equipment manufacturers have introduced new technologies such as six-wheel drive skidders, dual tire options, traction assistance, better power management through the drivetrain and additional drive axles on cut-to-length equipment R. Lawler, personal communication, 2 November 2023).

New equipment is also more expensive, requiring higher periods of uninterrupted operation to justify the purchase and consequently a larger timber tract portfolio. While the increase in productivity results in fewer hours needed to harvest a site, it results in the need to build more roads, landings and in-woods trails and to facilitate frost penetration on that infrastructure. Participants noted that the tracts that they harvest today tend to be on less well-drained sites that are farther from primary roads, necessitating more work to prepare the site for winter operations and building longer access roads that require more plowing so that they are snow-free to facilitate frost penetration. Science has continued to evolve, providing more information about the impacts of forest management activities such as timber harvesting on forest resources. In response, Minnesota's forest management guidelines now include compaction and rutting guidelines and metrics that define unacceptable rutting (Minnesota Forest Resources Council, 2014). Those guidelines, in combination with implementation of forest certification programs in most public ownerships in the state, may have made public agency foresters more restrictive today when administering timber sales.

Given the changes that loggers noted they face during their winter operations, there is a need to better understand the impact of those changes on forest managers and wood procurement staff and how they are adapting to the changing conditions. These latter individuals play a critical role in regional wood supply. Obtaining their perceptions about changing winter weather conditions can provide a more complete understanding of strategies for managing the supply chain from the forest to the mill during the winter logging season. This information could be useful to a variety of audiences, such as primary wood products mills, forest products equipment manufacturers and forest managers.

Conclusions

This study provided invaluable insights into whether and how winter weather trends are impacting Minnesota logging business operations in northern Minnesota. The preponderance of thought among focus group participants was that changing winter weather patterns are impacting their logging operations. Yet, there was no consensus that shifting weather conditions are the sole driver of their observed changes to winter logging, but an acknowledgment that their operations have changed over time due to a variety of factors. Several loggers cited various non-weather factors (e.g. larger and heavier logging equipment, increased pressure from timber sale administrators to minimize site impacts) driving the changes they have observed. Many feel these changes, which are not weather-related, influence the perception that dynamic weather conditions are driving changes to their winter logging operations. Regardless of whether loggers acknowledge or agree winter weather conditions are changing, both weather and non-weather changes have made winter logging more challenging now than in the past. The combined effect of these changes may begin to have a deleterious effect on the wood supply chain during winter in northern latitude states where a substantial percentage of wood is harvested during frozen ground conditions.

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