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Gaining Insights about Forest Health Prescriptions from Loggers and Foresters: Understudied Voices in the Human Dimensions of Forest Health

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Abstract
Maintaining healthy forests requires multiple individuals, including foresters who develop timber sale silvicultural prescriptions and loggers who implement those prescriptions, resulting in the transplantation of forest health science into workable management plans. However, data on the experiences, attitudes, and opinions of these two groups are often missing when developing or refining forest health treatment strategies. To explore the role that these groups play in sustaining forest health, we examined timber sale administrators' and loggers' perspectives on treatment approaches for eastern spruce dwarf mistletoe (*Arceuthobium pusillum*) (ESDM), a parasitic plant native to Minnesota that increases mortality and reduces growth rate and regeneration success of black spruce (*Picea mariana*). While ESDM has been managed for decades in black spruce stands in Minnesota, little is known about the effectiveness of the management approaches. Data were gathered through interviews and focus groups with loggers, as well as an online survey and focus groups with foresters who administer timber sales. Study participants identified a range of field-based barriers, knowledge gaps, and uncertainties that hamper the ability to effectively implement ESDM treatment strategies as designed, including financial, administrative, informational, policy-related, and environmental factors. These factors have a significant bearing on the ability to effectively implement ESDM treatment approaches; yet may be factors that were not known or considered when developing treatment strategies. This case study underscores the value of nurturing a science–management partnership to ensure that a broad set of voices are considered when developing or revising forest health treatment strategies.

Keywords Forest parasite · Silviculture · Logging · Qualitative data · Community of practice · Social science

Introduction

Sustaining forest health is a complex, multi-actor effort that involves a diversity of roles and activities related to the management of pests, diseases, and other disturbance vectors (Marzano et al. 2015). While much attention has been focused on the biological and ecological dimensions of forest health (Seidl et al. 2017; McDowell et al. 2020), less research has examined the human dimensions of forest health (Flint et al. 2009; Marzano and Urquhart 2018). Calls have been made in the research literature for enhanced focus on understanding the human side of forest health issues (Urquart et al. 2018). The research that has been conducted on the human dimensions elements of forest health has largely focused on the economic impacts associated with pests and disturbances (Holmes et al. 2009) and attitudes toward, management behaviors of, and impacts on stakeholder groups such as family forest owners (Molnar et al. 2007), community members (McFarlane et al. 2006), and outdoor recreationists and tourists (Arnberger et al. 2017). Other research has examined the general public's attitudes toward and acceptability of different forest health threats and treatments, including fuels reduction strategies (Shindler and Toman 2003) and forest pest control (Poudyal et al. 2016). However, there are additional voices that are less often considered in research but critical to the discussion of

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human dimensions elements of management decisions and practices related to forest health.

Two groups who play pivotal roles in supporting forest health are foresters who write silvicultural prescriptions that can include goals and objectives related to forest health and loggers who subsequently implement the prescriptions. In spite of the key roles these two groups play, little has been written about their attitudes, perceptions, and experiences related to forest health topics and the implementation of silvicultural prescriptions whose primary goal relates to forest health. The limited forest health research focused on loggers has examined their knowledge, attitudes, and practices regarding invasive forest plants (Snyder et al. 2020) and general views on their role in improving and maintaining forest health (Fellows 2015). Research on forester or timber sale administrators' perceptions and attitudes related to forest health prescription topics is similarly scant. Limited studies have focused on forest manager acceptability of and preferences for fuels treatments (McCaffrey et al. 2008), preferences for and perceived effectiveness of approaches to manage mountain pine beetle (*Dendroctonus ponderosae*) (McFarlane et al. 2015), and attitudes toward forest health priorities and concerns (Windmuller-Campione et al. 2019). We suggest this lack of research and broad understanding of the perspective of key players in the forest health arena represents a significant knowledge gap and a missed opportunity to gain valuable, on-the-ground insights that can be used to create or modify forest health management strategies to better reflect capabilities, capacities, and constraints by those who implement them.

As a case study to illustrate this information gap and gather valuable data, we examined logger and forester perspectives on treatments for eastern spruce dwarf mistletoe (*Arceuthobium pusillum*) (ESDM), a native, damaging plant pest of black spruce (*Picea mariana* (Mill.)) in Minnesota. ESDM causes its host to produce branch distortions (witches' brooms). It kills black spruce trees by diverting nutrients and water (Baker et al. 2006) and increases trees' susceptibility to drought and damage from insects and diseases, leading to the formation of mortality centers in stands (Baker and Knowles 2004). The presence of ESDM has also been found to shift species' composition, structure, and stand development, with lower black spruce density in the overstory and seedling layers in infected stands (Skay et al. 2021). It has been estimated that between 35 and 59% of black spruce stands in Minnesota may be infected with ESDM (Hanks et al. 2011; Baker et al. 2012).

Treatment of ESDM involves the removal of infested material, which is typically done utilizing a clear-cut system to mimic stand-replacing fires. The current management approach on state-administered lands in Minnesota is to remove (through harvesting or trampling) all standing live black spruce greater than 5-feet tall when ESDM is present (i.e., "5-foot rule") followed by removal of residual materials (Minnesota DNR 2019b). This rule has been in place for more than 30 years, but there has been little research to assess the effectiveness of this management approach to control ESDM or monitor its implementation success. Research is also lacking in understanding the attitudes, experiences, and perceptions of those who prescribe ESDM treatments (i.e., foresters and timber sale administrators) and those tasked with carrying them out (i.e., loggers). Our research is focused on assessing loggers' and timber sale foresters' perceptions of the effectiveness of ESDM management strategies and practices and barriers to treatment in black spruce in Minnesota. Given their role in the implementation of forest health prescriptions, they have important experiences and insights which could inform treatment strategies for ESDM in Minnesota, as well as potentially informing treatment strategies for different species of dwarf mistletoe (DM) in other forest types.

Methods

Study Region

Our study area focused on three northern Minnesota counties (Itasca, Koochiching, and St. Louis) that collectively produced 94% of the black spruce volume harvested by county land departments between 2016 and 2018 (Minnesota DNR 2017, 2018, 2019c) (Fig. 1).

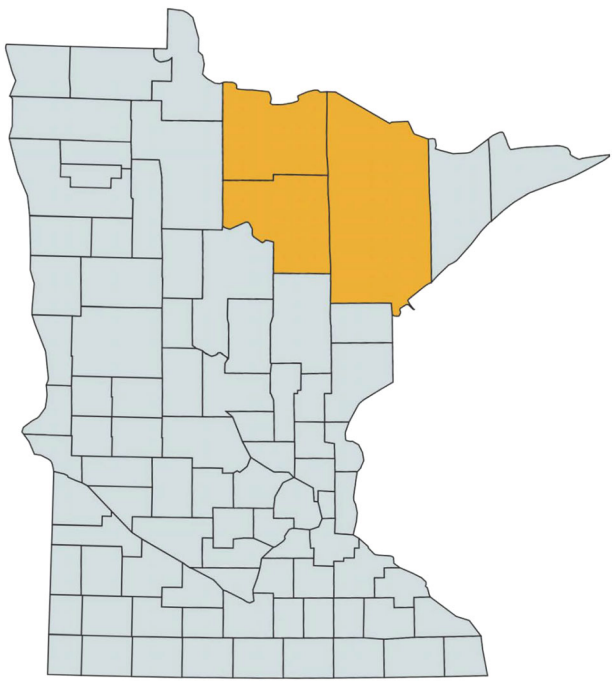

Fig. 1 Map of Minnesota with the three study counties highlighted. Created using mapchart.net©

Study Design

A mixed-methods approach was used to gather insights from foresters and loggers who work within the study area. An online survey was administered to foresters using Qualtrics©, 2019 version (Qualtrics Software, 2019). Data were also gathered through interviews and focus groups with loggers, as well as focus groups with foresters who set up and administer black spruce timber sales. In addition to confirming and amplifying responses to the survey questions regarding treatment barriers, the qualitative data collection efforts allowed for deeper probing into some responses that were offered in open-ended comments in the survey but not directly queried about in the survey. Given that ESDM is the only dwarf mistletoe (DM) native to Minnesota and the only one which is impacting black spruce, all of the data collection efforts used the general language of DM rather than a specific species name. The University of Minnesota's Institutional Review Board reviewed the protocol for the project and determined it was exempt from further review.

Logger Interviews

A list of logging business owners who bought black spruce timber sales in the study area between 2015 and 2018 was compiled from county land departments, state Department of Natural Resources (DNR) offices, and forest products companies. Contact information for each owner was found on the public Minnesota Logger Education Program's (MLEP) member database (Minnesota Logger Education Program–Logger Member Search 2020). In total, 43 owners were contacted, with ten agreeing to be interviewed. Interviews were conducted between October and December of 2018 and lasted between 20 min and 1 h, averaging 32 min.

Logger Focus Groups

Following the interviews with logging business owners, focus groups were conducted to continue to probe and triangulate findings. The same list of owners in the study area who had purchased at least one black spruce timber sale within the past three years was used to recruit focus group participants. Given the small population of loggers in the study area, the sampling strategy was done with replacement. Continuing education credits for focus group participants were provided as an incentive by MLEP. Three focus groups were scheduled to be concurrent with the MLEP annual conferences to increase participation. Additional key in-woods logging personnel who had relevant experience with black spruce timber sales within or adjacent to our study counties were recruited in person at the MLEP conferences. In total, 34 individuals, hereinafter referred to as loggers, agreed to participate in the three focus groups. Three of the focus group participants were also interviewees. Focus groups were conducted in April 2019 in Bemidji and Duluth, Minnesota, and averaged 80 min.

Table 1 Distribution of foresters by employer who were sent and returned the forester survey ($n = 194$)

Employer	Number sent (%)	Number returned (%)
Minnesota Department of Natural Resources (DNR)	116 (60)	61 (56)
County agencies	44 (23)	33 (31)
USDA Forest Service	25 (13)	7 (6)
Industry	5 (3)	4 (4)
Tribal	4 (2)	3 (3)
Total	194	108

Forester Survey

Contact information of foresters who set up and administer timber sales in the study area was compiled from public organizational staff directories and personal contacts. In total, 194 foresters were represented in the sampling frame (Table 1). The survey included 48 questions and addressed the following topics: (1) familiarity with and ability to identify DM, (2) perspectives on the effectiveness of the DM prescription, (3) impediments to ESDM treatment implementation, (4) information, training, and assistance needs relative to DM, and (5) respondent demographics.

An adapted Dillman's method (Dillman et al. 2014) was used in implementing the survey. Each forester received an email message with a personalized link to the survey. Two email reminders each about three weeks apart followed the initial invitation, which also included the survey link. The personalized link ensured that only the intended recipients of the survey had access in order to control the sampling frame. The survey was administered between April and June 2019. Nine emails were undeliverable. After the three survey waves, 108 responses were recorded, for a 58% cooperation rate. Survey responses were automatically coded within a Qualtrics database. Descriptive statistics were conducted using the SAS© version 9.4. See Snyder et al. (2021) for complete details about the forester survey design, implementation, and analysis.

Forester Focus Groups

Focus groups with foresters were conducted to probe for a deeper meaning in the survey responses. The same contact list as used for the forester survey was used to recruit foresters for the focus groups. Maximum variation purposive sampling was used to ensure focus groups included participants with

varying experiences and characteristics (Patton 2014), such as agency type, geographic location, years of experience, and whether they had completed the forester survey. Sixty-nine foresters were contacted and seventeen agreed to participate. Of the focus group participants, 14 had completed the survey.

Focus groups were conducted in the towns of Grand Rapids, Tower, and International Falls, Minnesota in October 2019. The focus group guide included questions about administering sales containing DM, DM treatments prescribed and perceived effectiveness of them, experiences and perspectives around pre- and post-treatments for DM, and coordination of management regarding sales with DM. Focus groups lasted on average 1 h and 45 min. See Roth et al. (2021) for complete details about the interview and focus group topics and data collection.

Qualitative Data Analysis

Qualitative data were analyzed using open coding consistent with adapted grounded theory procedures (Charmaz 2006; Corbin and Strauss 2008). All interviews and focus groups were audio-recorded, transcribed verbatim, and proofread. The three qualitative data pieces (logger interviews and focus groups, forester focus groups) were analyzed together as a single data corpus. One researcher conducted the open coding, which involved reading line by line through each interview and focus group and assigning each sentence one or more codes representing a key idea. Open coding allowed the codes and ideas to emerge from the data, rather than using pre-determined codes, themes, or ideas to evaluate the data. After coding, data were grouped into larger concepts and categories in order to find common themes and relationships, as well as diverging themes. By combining the three qualitative data collection efforts, we could triangulate a coding schema and findings during the open coding process. All three researchers participated in discussions about the themes that were emerging and discussed the coding structure that was being used during the coding process. QSR International's NVivo 11 software was used (QSR NVivo 2016).

Results

Survey Non-Response Bias Check

Comparing the rates of returned surveys by the organization to the percent sent to foresters in each organization illustrates that county agency foresters were over-represented in the responses, while federal foresters were under-represented (Table 1). A non-response bias check was conducted by comparing early (first 25%) to late survey responders (last 25%) as a proxy to detect differences between respondents and non-respondents based on the assumption that non-responders are similar to late responders (Armstrong and Overton 1977). Specifically, the responses to questions examined between early and late respondents included: level of DM knowledge, confidence in the ability to identify DM, confidence in the ability of appraisal methods to detect DM in a stand, confidence in stand assessment method to detect DM in a stand, degree of concern about DM in their work area, degree of concern about DM impacts to the ecological health of black spruce, degree of concern about DM impacts to black spruce timber production, number of years working in the forestry field, number of years setting up black spruce sales, and the percent of their timber sales in the past year with DM. Two statistically significant differences were found. Early responders ($M = 10.7$, SD = 9.9) had fewer years working in the forestry field than late responders ($M = 17.5$, SD = 10.8), $t(50) = 2.36$, $p = 0.022$. Early responders ($M = 5.2$, SD = 3.9) also had fewer years of experience setting up black spruce timber sales than late responders ($M = 11.9$, SD = 11.5), $t(31) = 2.81$, $p = 0.009$. The results should be viewed with these differences in mind.

Participant Profiles

Logger participants in interviews and focus groups were all white males (Table 2). Majority of participants had completed high school or their GED, at a minimum. The average number of years participants had been logging was 36 (interviews) and 27 (focus groups) (Table 3). Forester

Table 2 Logger and forester sociodemographic characteristics

Characteristic	Logger interviews ($n = 10$)		Logger focus groups ($n = 34$)		Forester focus groups ($n = 17$)	
Age	Mean: 47 Range: 36–63		Mean: 46 Range: 22–69		Mean: 36 Range: 25–48	
Gender						
Male	10	100%	34	100%	13	76%
Race						
White	10	100%	34	100%	17	100%
Level of formal education						
Did not finish high school	0	0%	1	3%	0	0%
Finished high school/GED	3	33%	17	50%	0	0%
Some college, no degree	2	22%	6	18%	0	0%
Associates or vocational degree	2	22%	5	15%	1	6%
College bachelor's degree	2	22%	3	9%	15	88%
Some graduate school	0	0%	1	3%	0	0%
Completed graduate degree (MS or PhD)	0	0%	1	3%	1	6%

Table 3 Logger business characteristics

Characteristic	Interviews ($n = 9$)		Focus groups ($n = 34$)	
Years logging	Mean: 36 years Range: 20–58 years		Mean: 27 years Range: 5–50 years	
Years with current business	Mean: 30 years Range: 8–45 years		Mean: 24 years Range: 5–49 years	
Winter in-woods employees				
≤5	3	33%	17	50%
6–10	2	22%	9	26%
11–20	2	22%	2	6%
21–30	2	22%	2	6%
30+	0	0%	2	6%
Annual harvest (cords)				
≤5000	0	0%	8	24%
5001–10,000	1	11%	3	9%
10,001–15,000	0	0%	8	24%
15,001–25,000	4	44%	5	15%
25,001–50,000	4	44%	6	18%
50,001–100,000	0	0%	2	6%
100,000+	0	0%	1	3%

Table 4 Forester role characteristics

Characteristic		*n*	%
Agency/organization	State	11	65
	County	5	29
	Federal	0	0
	Private industry	1	6
Years working as forester		Mean: 9.6 years Range: 2–22 years	
Years working for current employer		Mean: 7.8 years Range: 2–20 years	
Years working with black spruce		Mean: 8.2 years Range: 2–20 years	

participants in focus groups were all white, and 76% identified as male. All participants had at minimum a college bachelor's degree (Table 2). About two-thirds of participants worked for a state-level agency (65%) (Table 4). The average number of years participants had been working as a forester was 9.6 years, and 8.2 years working in the black spruce forest type specifically.

Forester and Logger Perceptions of Barriers to DM Treatment

Questions about perceptions of barriers to DM treatments were asked in the survey, interviews, and focus groups. In evaluating responses over all of these data collection efforts, major themes emerged related to the barriers or obstacles to implementing DM treatments from both foresters and loggers that are summarized below.

Financial barriers

Loggers and foresters both emphasized that a major barrier associated with implementing DM treatments is the cost burden, particularly for loggers. A key component to most DM treatments is cutting or running down small, unmerchantable black spruce stems as required by the 5-foot cutting rule. This requirement is one of the main frustrations for loggers as it is extremely resource intensive (in terms of time, fuel, and wear and tear on equipment) to ensure those stems are felled or broken off, resulting in reduced profit margins. Foresters realize that this requirement is an impact to loggers; nearly 75% of respondents to the forester survey chose loss of production due to additional time necessary to implement DM treatments as one of the top three barriers faced by loggers in effectively implementing DM treatments (Table 5). One logger shared his frustration with this:

> If we're cutting a bunch of non-merchantable species, my buncher runs ten hours a day. For three of those hours it's dealing with non-merchantable species or stems that we're just putting in the ground. Then I'm losing all that production to what could be actually usable product on a different site. There's definitely a cost there.

Equipment damage was identified as a common occurrence when cutting small black spruce stems. Loss of logger production due to impacts on equipment caused by implementing DM treatments was identified by 21% of forester survey respondents as a perceived barrier to DM treatment implementation by loggers. Loggers amplified this sentiment:

> Sometimes we rent a little newer equipment and you kind of hate to go beating your machine through that stuff where–about five, six foot high–you got spears going everywhere, scratch the paint, rips the hoses right off in the radiator area.

Table 5 Forester perceptions of barriers that most affect loggers' ability to effectively implement dwarf mistletoe treatments ($N = 92$)

Barrier	Percentage of respondents who selected the barrier as one of their top three
Loss of production due to additional time required to implement treatment(s)	73
Poor black spruce ground conditions due to weather (e.g., winter too warm for ground to freeze)	61
Loss of production due to impacts on equipment caused by implementing treatment(s)	21
Inadequate communication regarding treatment requirements	20
Inadequate equipment to implement treatment(s)	18
Harvested/merchantable volume does not approximate appraised volume	18
Inadequate information on dwarf mistletoe identification	11
Other[a]	8

Percentages add to more than 100 because respondents could choose up to three barriers

[a]"Other" barriers identified were (a) low merchantable volume in dwarf mistletoe pockets can result in less effective treatment, (b) poor black spruce markets, and (c) sales that are difficult to access

Limited agency budgets to adequately address DM treatments were identified as a financial barrier for foresters and their agencies. Over 60% of survey respondents identified insufficient agency time or financial resources to address DM treatment as a financial barrier to DM treatment, with an additional 21% of respondents indicating insufficient time or financial resources for follow-up monitoring as a treatment barrier (Table 6). One forester shared:

> If we can't get it done by the person cutting the wood…we're not gonna pay someone. We just don't have the resources, it's not in our management to shear black spruce, so generally we try to get stuff done with the person harvesting.

Weak spruce markets

Fluctuating black spruce markets or lack of markets was another barrier cited by loggers and foresters in their efforts to implement DM treatments. As shared by respondents, the black spruce market in Minnesota has been challenging as one mill closed and another reduced its purchases in recent years. If loggers do not have markets to sell their harvested product to, there is less incentive to purchase some species and to ensure every stem on a sale that they purchase is cut as prescribed. In addition, there is no longer a strong chipping or biomass market in Minnesota. When that market existed, it was possible for loggers to make some profit off the small, unmerchantable stems they were required to cut in stands containing DM. Now there is no market for these trees. One forester added, "When markets are weak for spruce, then we can't do as much management in spruce…just because they [loggers] won't bid on it."

Foresters also felt that markets can have an impact on how effectively loggers implement DM treatments. While markets were not one of the response options that foresters could choose as a barrier in the survey, several survey respondents identified it as a barrier in open-ended responses. When black spruce markets are weak, profit from a black spruce timber sale may be reduced which could incentivize a logger to look for ways to not fully implement a treatment, as shared by this forester: "When money is tight…you're less likely to do anything and you're really grumpy about it." On the other hand, when black spruce markets are good, loggers are making more of a profit on these sales and are more likely to implement the treatment exactly, as shared by this forester:

> Yeah markets will play a lot in that – and that's cyclical and markets are great. You're getting paid a fair wage to do your job. Loggers are making money. They're updating equipment. They're in a better mood. They're willing to do that extra thing because they know it's the right thing to do.

Lack of coordination on adjacent stands

Lack of DM treatment coordination on adjacent stands was also discussed by both loggers and foresters as a barrier to effective DM treatment. It is of note that it was not a topic that was specifically asked about in any of the data collection efforts, but rather was offered spontaneously by respondents in response to other questioning. For example, if a logger is harvesting a sale with DM that directly borders an infected stand that is owned by a different land management agency or landowner and not being harvested, respondents indicated that the harvested stand is likely to be reinfected as it regenerates. Foresters shared that there is no policy that requires them to communicate with or notify other landowners regarding the sale of bordering stands:

"You don't have a policy where you have to notify adjacent landowners with mistletoe. So it's up to the individual forester to do it." In addition, even if foresters or landowners do notify each other, it does not mean there will be action because of it. One forester shared:

> You can't necessarily make somebody cut their stand if they don't want to. So I think a lot of times…there would always be that cooperation and understanding, but there's times where you don't have that ability to control that aspect of the harvest.

Differing sale schedules, land management objectives, and sale planning requirements were cited as obstacles to coordination. Another perception, related to the lack of coordination on adjacent stands, is that cyclical infections that move from one stand to another and back to a treated stand limit the effectiveness of treatments. Loggers and foresters repeatedly described this concern when discussing the effectiveness of treatments. One logger shared that they do not know how effective their DM treatments are because of the ownership differences across the landscape:

> If one agency cuts theirs, the stand right next to it might be infected and doesn't get harvested for several years. And the regen comes on the site that was harvested…does that infected stand that's besides it carry over and affect the stand regrowth?

Varying treatment approaches across landowners and foresters

Loggers and foresters described variability or inconsistency in DM treatment approaches among land management agencies being a barrier to effective treatment implementation. Loggers expressed frustration that there is inconsistency in what they are asked to do on black spruce stands with DM. For example, some treatment specifications may call for removing all black spruce over 5-feet tall in any black spruce harvest regardless of known DM infestation, while others will only require it when DM is present. As another example, some treatment specifications will require implementation on an entire black spruce harvest tract, while others will only require the 5-foot rule in specific marked areas of the harvest. One forester said, "The enforcement of what we're asking for people to do definitely changes in the heart of where the black spruce mistletoe is. [My agency], we're definitely more apt to require certain things and get to the edges [of an infected stand]."

In addition, loggers described experiences of varying flexibility of the rules even within one agency depending on which forester administered the sale, Some loggers attributed the differences among foresters to age and experience. One logger said:

> New foresters are learning different things in school. For example, wildlife, invasive species, climate change. But they don't have the field experience. They need to learn how to manage "gray areas." It's not black and white decisions.

Loggers also described working with private landowners who had DM in their forest stands and the different preferences those landowners can have. Many loggers suggested private landowners mostly just want to maximize profit when having trees harvested on their land, as one logger described: "I've logged spruce and they never mentioned anything about [mistletoe]…they just want to see how many dollars they can get…nobody's ever mentioned mistletoe…it's all about the money."

Impacts of ground conditions

Loggers and foresters both discussed the difficulty of loggers needing to harvest a large percentage of their black spruce sales in the winter when the ground is frozen. The second most common factor, selected by 61% of forester survey respondents, as a perceived barrier to loggers in implementing DM treatments was poor black spruce ground conditions due to weather (e.g., winter too warm for ground to freeze). While foresters are assigning sales as "winter only" to avoid rutting or other environmental concerns, it is increasingly difficult for loggers to accomplish so much in a short timeframe. As one logger shared:

> The winters are getting warmer and warmer. The last winter we had an exceptionally good winter, but winters is a lot of it. The environmentalist people, this and that, and there are rules on some of our spruce ground…it's tough. We can't get to it because it's too wet.

Dwarf mistletoe is not a concern

Despite the discussions of impacts on forest health and the timber industry, there were some loggers and foresters who felt that DM is not very concerning. Some based this opinion on the fact that it is native and has been here as long as they can remember, and is thus viewed as a "normal" pest. Loggers and foresters also shared that it is something they have always dealt with and are comfortable dealing with, so it really is not a problem, as described by this forester: "Mistletoe isn't going that fast. It will be here in 100 years. It will be here over there in 200 years. Is it that big of a deal?" One logger was asked if he was concerned about DM and responded:

> No, not really, but what do you do? There's nothing you can do about it. If I can do something to help and prevent it, okay, fine and dandy. But if they're not going to do something about it, if the agencies or the government aren't going to buy anything to kill it off, then that's the way it is. What do you do?

Other loggers and foresters highlighted the fact that there are many other forest pests and diseases they are dealing with that are of much higher concern to them than DM, including the eastern larch beetle (*Dendroctonus simplex* LeConte), emerald ash borer (*Agrilus planipennis* Fairmaire) (EAB), and eastern spruce budworm (*Choristoneura fumiferana* Clemens). One logger said: "I've never heard them make a big stink about mistletoe versus like bark beetles or something in the pine, they talk about that stuff all the time. Mistletoe doesn't get talked about a whole lot." Another forester said that while DM can cause mortality, "It's not going to annihilate a forest like larch beetle."

Lastly, there were discussions among some of the foresters about the positive impacts DM can have, such as creating structural diversity and wildlife habitat within a stand. One forester said that DM could be considered:

> …as a good thing. Increased cranberries for the red squirrels. And blueberries. And you might even see a white pine come into one of those death pockets, just because you don't have flooding out, so you can maybe get some diversity.

Forester and Logger Perceptions of DM Treatment Effectiveness

Questions about perceptions of DM treatment effectiveness were included in the survey, interviews, and focus groups. Themes related to treatment effectiveness are summarized below, and focus on uncertainty about treatment goals and outcomes.

Uncertainty about goals for treatment outcomes

Loggers and foresters shared that there is not a common definition or shared understanding of what DM treatment effectiveness means or what a desired or feasible treatment outcome should be. Many foresters felt that if the DM treatment is implemented as designed, then that equals an effective treatment. One forester shared: "I consider it effective if the logger complies and it looks good for me at the end…All we can really do is make sure that what we ask the logger to do actually got implemented." Other foresters felt treatments are only effective if, in the long term, there is a success with the eradication of DM, as shared by this forester: "The best way to tell is…long term monitoring. It's going into these second growth stands now and seeing that there's regen." Yet other foresters said simply if you kill the trees containing DM, you are effective in its control: "You're killing more stems and that kills mistletoe, so that's effective right?"

Other foresters focused more on timber production and felt if the wood is being salvaged that would have otherwise died if left, that is an effective treatment. Similarly, if the trees can make it to a harvestable level, even if containing DM, that could be considered effective. Most foresters agreed, even without a definition of effectiveness, doing something about DM is more effective than doing nothing, as shared by this forester:

> Effectiveness, again, it's hard to say. I think it's a matter of mitigating or minimizing your risk. And, that's all you can do when that's what we're after is just trying to get the stand as healthy as possible and give it as much chance as we can afford. Whether it's effective or not, I'm sure it's more effective than doing nothing.

Uncertainty about treatment effectiveness

At least half of the forester survey respondents indicated that the four most common ways to implement the 5-foot rule and establishing a harvested buffer strip between infected and non-infected stands were all reported to be somewhat to very effective (Fig. 2). Severing all black spruce stems over 5-feet tall, with or without DM present, was the only treatment in which at least 20% of the respondents reported that it was very effective. However, there was also a fair amount of uncertainty expressed about treatment effectiveness. The percentages of respondents uncertain about the effectiveness of different treatments ranged from 15% for harvested buffer strips between

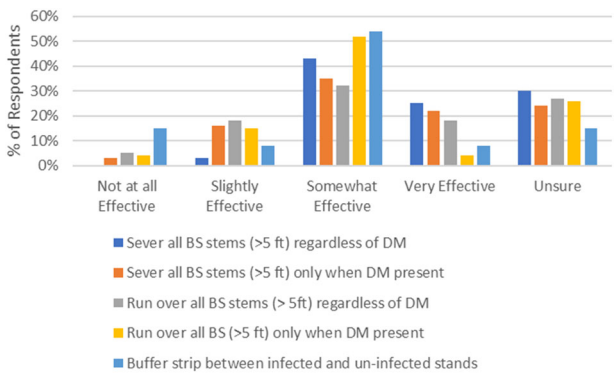

Fig. 2 Perceived effectiveness of overall dwarf mistletoe management efforts statewide according to the forester survey (*N* varies)

infected and non-infected stands to 30% for severing all stems over 5-feet tall regardless of DM presence in a black spruce stand.

Respondents indicated that the relatively long rotation length of black spruce contributes to uncertainty regarding long-term DM treatment effectiveness. Stands being harvested now likely will not be set up to sell again for at least 80 years, in which a new forester will be the one setting up the sale. When loggers were asked about how they measure their effectiveness of DM treatments, one said, "I don't know. I have no answer for that. Is it effective or isn't it effective? I do not know. I'll never know because it takes 100 years for that stand to reach maturity."

Foresters also shared that they are just assuming their treatments are working, but do not always know or have data to show it is. They described how long they have been dealing with DM and treating it, yet still have it throughout their managed forests. One forester described their perspective: "[Foresters] are assuming what we are doing is working…that's a big assumption." Similarly, foresters shared they generally do not know what was done to manage stands historically because there are not always data or records from decades back on DM levels or treatments used, as one forester shared: "I think a lot of it is record keeping. I mean, even if we did make a considerable effort now, I'm not sure we have the data from the previous harvest to know was there mistletoe in the stand before that harvest."

In addition, while foresters do go into stands between harvests for regeneration checks, they said they typically are not checking specifically for DM. Instead, they are assessing whether the stand has sufficient levels of black spruce regeneration (number of stems per acre). Also, if they are looking for DM but it is only 5–10 years post harvest, the DM might not be easily visible yet even if it is present, as described by this forester: "We do a regen checks at five years, so maybe people aren't sure if it's been effective or not, because it might be 15 years to see it."

Some foresters shared they or their agencies did not want to spend any additional money on treating DM unless they know things are effective, as described by this forester:

> We're not going to try to spend the money to do it if we don't think it's effective. I don't think we're going to eradicate it from a site…maybe we're just living with the fact that there is mistletoe on the site, so why spend the extra money?

Finally, foresters described a need to treat DM at the landscape level, rather than the stand level, if they hope to make progress in management. When asked about needs foresters have in order to improve the effectiveness of treating DM, one forester said:

> Larger cuts I think. A specific treatment change is just to go big. I mean, even if it's not up to rotation, it's only 60 years old, and it's better just to go big and actually treat an area versus a stand. Treat the landscape [instead] of the stand.

Discussion

A number of impediments to implementing DM treatments, for both loggers and foresters, were identified in our study, including financial, administrative, informational, policy-related, and environmental factors. These factors have a significant bearing on the ability to effectively carry out DM treatment approaches; yet may be factors that were not known or considered when developing treatment strategies. The identification of these barriers reinforces our contention that feedback and perspectives may be missing in the development or modification of forest health treatment approaches. As outlined by Roux et al. (2006), it is important to develop partnerships and communities of practice in which there are bidirectional flows of knowledge and information between scientists and managers so that strategies, plans, and techniques can be updated as understanding involves. Similarly, Ayres and Lombardero (2018, p. 297) emphasized the value of an adaptive management approach to forest health where "managers, scientists, and decisionmakers collaborate such that that there can be steady improvements in management efficacy." In the case of DM in black spruce, loggers and foresters are critical to the process of translating forest health science into workable management implementation. We outline potential strategies for addressing knowledge gaps, implementation barriers, and uncertainties raised by study respondents that could help inform adaptive management strategies for DM in black spruce stands.

Need for Additional Incentives

Loggers feel that the burden of implementing DM treatments, particularly the removal of many non-merchantable stems, falls to them without mechanisms to adequately compensate them for their additional costs. That issue influences their interest in bidding on black spruce timber sales. Our findings suggest that when the 5-foot cutting rule was conceived, there may not have been an understanding of the financial reality and practicality of loggers being able to implement it. Suggestions made by loggers to make it more worth their while to implement DM treatments included being compensated for the removal of non-merchantable stems which may be comparable to paying for precommercial thinning activities (Hiesl et al. 2015),

reduced appraisal values (Brown et al. 2013; Russell et al. 2017), or creating timber sales with more volume which include DM-infected wood with nearby uninfected merchantable trees to allow them to spread their fixed costs over more units of production and reduce the overall impact of increased costs to their operation (Kueper et al. 2014; Russell et al. 2017). Because the change in logging productivity due to the additional time and cost to implement DM treatments has not been quantified, research to gather this information could be useful in helping to estimate incentive levels needed to compensate loggers for the impact of implementing DM treatments.

Impact of Markets

Lack of strong markets for timber products is a common concern of loggers, and a factor that constrains a variety of logging activities (Fielding et al. 2012; Pelkki 2012). Markets are critical to implementing DM treatments, which is a complicating element of this particular forest health issue. Without strong timber markets, commercial harvesting will not occur. Specifically, weak spruce markets means that it has become increasingly difficult for loggers to find markets for their harvested black spruce. A major decline in biomass use for energy production in Minnesota (Minnesota Department of Natural Resources 2020) means there is no market for the unmerchantable stems that have to be cut in DM prescriptions, which is also a deterrent to loggers felling non-merchantable stems. All of these factors can negatively impact logger interest in bidding on black spruce sales with DM that constrains the ability to treat DM. There is no simple fix to address this market issue. However, it is important to raise awareness that with declining market capacity, it could become more difficult to manage DM in black spruce in the future under current treatment approaches.

Institutional Barriers

Respondents told us about inconsistencies in how different organizations approach DM treatment and institutional barriers that hamper coordinated efforts that limit the ability to effectively control DM across the landscape. The need for coordination in forest health treatment approaches is not unique to DM. For example, the Minnesota Forest Resource Council's landscape forest resources plans, which include the three counties where data were collected, all identify the need to coordinate control efforts for forest pests and invasive species across jurisdictional boundaries (Minnesota Forest Resources Council 2010, 2014, 2017). Institutional barriers have been identified by others as an impediment to forest health management, particularly at a landscape scale (Oliver et al. 1994). Jurisdictional issues, agency silos, and conflicting goals among different levels of government have impeded effective treatment and control of EAB (MacQuarrie et al. 2015) and mountain pine beetle (Abrams et al. 2017) at the landscape level in Canada. Improved treatment coordination across ownership and stand boundaries is viewed by many study participants as essential in order to ensure treatments are not in vain and harvested stands will not be immediately reinfected.

A unique issue that was identified in our study was the difference in disciplinary perspectives between foresters and wildlife biologists regarding the impacts/value of DM and associated treatment of it. Minnesota's forest management guidelines within a clear-cut area recommend retaining live (leave) and snags (dead) trees to provide for wildlife requiring perches, tree cavities, and bark-foraging sites (Minnesota Forest Resources Council 2013). Given that black spruce is commonly clearcut, retaining leave trees for wildlife purposes is counter to the 5-foot rule and may result in residual pockets of DM-infected trees. This tension between forest health and wildlife benefits may not have been considered when developing the 5-foot cutting rule and highlights the importance of engaging a diverse set of actors and incorporating feedback in developing forest health approaches. Better dialog between foresters and wildlife biologists is needed when designing black spruce timber sales so that more nuanced or site-specific management approaches can be developed that support both forest values in ways that do not promote unintended spread of DM. As well, data on the impact of leave trees to the spread of DM would be useful in informing this discussion.

Environmental Conditions

Loggers discussed warming winters and the difficulties it poses for cutting black spruce, which echoes findings from Geisler et al. (2016) and Tevfik et al. (2021) about the impact of seasonal environmental conditions on logging operations. As the harvesting of black spruce usually occurs during the winter due to the need for frozen ground, warming winters may lead to a shorter timeframe to access and harvest black spruce stands, reducing the amount of area which can be treated for DM. While agencies have provided extensions on their timber sales to allow additional time to harvest black spruce stands, the additional time may increase mortality within the stand and further decrease merchantability. This could draw loggers away from black spruce sales and toward species that can be harvested in winter more dependably.

Increasing Confidence in Treatment Effectiveness

Both foresters and loggers are unclear about what an attainable outcome of DM treatments should be, and both report a lack of certainty or confidence that treatments (and

Table 6 Forester perceptions of barriers that most hinder their/their organization's ability to effectively implement dwarf mistletoe treatments ($N = 92$)

Barrier	Percentage of respondents who selected the barrier as one of their top three
Insufficient time or financial resources to adequately address treatment/management	62
Inadequate information on dwarf mistletoe impacts	23
Insufficient time or financial resources for follow-up monitoring	21
Inadequate equipment to implement pre- or post-treatment(s)	15
Lack of loggers/buyers to implement treatment(s)	13
Black spruce sales not selling on auction/sales	12
Lack of loggers/buyers with appropriate equipment to implement treatment(s)	11
Lack of enforcement abilities/penalties	9
Inadequate information on dwarf mistletoe identification	7
Other[a]	28

Percentages add to more than 100 because respondents could choose up to three barriers

[a]"Other" barriers identified included (a) overall timber sale or harvest volumes in some areas too low to offer a timber sale, (b) conflicting values within an organization (e.g., retaining residual trees for diversity and wildlife habitat on a harvest site where DM is present), (c) adjacent stands with DM are not being harvested, and (d) inadequate follow-up post harvest

post-harvest treatments) are working. Because of this uncertainty, foresters reported being hesitant in seeking funding for and/or undertaking post-harvest treatments as well as prioritizing additional DM treatments over other forest health activities.

A variety of suggestions emerged for improving treatment effectiveness or at least confidence in treatment effectiveness. First, better electronic records of treatments that would allow for tracking of treatments and outcomes over time. Long-term monitoring specifically for the effectiveness of treatments, not just regeneration checks, was also suggested. As mentioned previously, research that documents the effectiveness of treatments is also imperative.

Finally, there is a need to define what "success" is when managing DM as there are unanswered questions from field practitioners when it comes to understanding treatment effectiveness. Is success: (a) eradicating DM from the stand, (b) cutting down every stem, or (c) just minimizing DM impacts while getting black spruce to a harvestable age? The means to achieve each of these outcomes, if achievable at all, are not the same and this creates confusion and inconsistency in efforts to control DM. What does effectiveness look like post-harvest, as well as ten years post-harvest during regeneration checks? Are the treatments used for management (e.g., the 5-foot cutting rule) based on evidence of success? Research and monitoring could help fill that gap, as well as develop communities of practice among scientists, managers, and loggers to have a two-way dialog about what is a desirable and feasible outcome of DM treatment across the landscape. Of note, however, was that most of the loggers in our study did not convey information about their experiences with DM back to foresters. Most just indicated they did what they were asked to do regarding DM treatment and it was the forester's job to determine whether treatment efforts were effective. One logger shared: "We're bound by the sale so we can't argue with foresters." While another logger similarly said: "We usually follow the orders that they give, and that's the end of it." In one exception, a logger shared that they convinced an agency to shear an infected black spruce site that was outside of a sale area. This action happened because the logger had a relationship with the forester, sharing that: "I stirred the pot. Well I hope it gets done, from what they told me it's kind of a pilot project to see what comes of it." Our research suggests that while loggers and foresters have important field experiences to share, work is needed to create a feedback system or community of practice in which they can share their experiences, concerns and questions regarding DM treatment approaches and outcomes with each other, scientists, and policymakers who create guidance documents for addressing forest health issues.

Conclusions

Results from this study suggest that there are many important lessons that can be learned from foresters and loggers who are tasked with prescribing and implementing silvicultural-based forest health treatments. Our study identified information and knowledge gaps regarding DM treatment and a need for a review of commonly prescribed, long-held approaches to DM treatment. Our research suggests that applying the best-available science to develop forest health prescriptions to address a forest health issue such as DM does not necessarily mean that implementation

will be successful if the individuals responsible for implementing the treatment have impediments that were not adequately considered during the formulation of the strategy. The best-designed plans for control may fail or be difficult to implement if field-level barriers hinder the ability to affect control.

The breadth and capability of tools and approaches for assessing and monitoring forest health have increased over time (Bechtold et al. 2007; Randolph 2013; USDA Forest Service 2020). Using the best-available science, strategies have been developed for managing many species of concern (e.g., USDA Animal and Plant Health Inspection Service 2019, 2020). The combination of assessment tools, monitoring techniques, best-available science, and strategies create a seemingly powerful approach for managing forest health issues. However, as our study found, there can be unforeseen or unappreciated barriers to effective forest health implementation if the perspectives and experiences of those tasked with carrying out forest health prescriptions are not heard. Moreover, as we discovered in this study, uncertainty about what is a feasible or desirable outcome of a forest health prescription creates challenges for both treatment implementation as well as preparation of the prescription itself. Participants in our study highlighted a lack of shared understanding of treatment goals, outcomes, and effectiveness between scientists, managers, and practitioners. These are important findings that suggest more dialog and information sharing is needed among the full set of actors responsible for sustaining forest health. These efforts would be beneficial for work on other forest health issues as well.

One of the motivating reasons for focusing on ESDM in our case study is because there is an invasive DM species, lodgepole pine dwarf mistletoe (LPDM) (*Arceuthobium americanum*), that is poised to spread into Minnesota from Canada that would have serious ecological and economic impacts on jack pine (*Pinus banksiana*). The insights we learned about treating ESDM from loggers and foresters may be helpful in informing treatment strategies for LPMD if and when it arrives in the state. However, different timing (e.g., season of operation), intensity, and/or types of treatments may be needed to deal with LPDM, and thus additional research with loggers and foresters who conduct harvests in jack pine would be useful in informing treatment approaches. We also suggest that foresters and loggers could provide valuable field insights about silvicultural-based treatment strategies for other forest health threats, including bark beetle (*Dendroctonus* spp.) (Windmuller-Campione et al. 2021) and white pine blister rust (*Cronartium ribicola*) (Burns et al. 2008).

Our research supports and contributes to the body of research calling for greater bridging of the scientist-manager divide and co-production of research needs and information as has been emphasized in other forest management applications. Nagel et al. (2017) acknowledged challenges associated with designing silvicultural adaptation strategies in the face of climate change, calling for partnerships between managers and scientists that provide a platform for managers to identify innovative forest management strategies based on field experiences. Oliver et al. (1994; p. 129) emphasized the importance of a feedback loop in forest health strategies, calling for the forest health community to "practice adaptive management techniques to be in a position to modify actions and prescriptions as new feedback information becomes available." Our study illustrates that there is an important need to ensure that the on-the-ground experiences and perspectives of those tasked with implementing forest health treatments are considered when assessing, reviewing, and, if needed, modifying treatment prescriptions for forest pests and diseases, as well as identifying knowledge gaps and research needs. Practitioner perspectives and on-the-ground experiences are an important part of a feedback and learning loop regarding forest health management approaches. Listening to the voices of those responsible for implementing forest health prescriptions, such as the foresters and loggers engaged in treating DM in our study, could help ensure that forest health management strategies consider the broader context in which forest health efforts are situated and the set of actors involved. In the long term, these efforts could enhance our ability to better manage forest health issues.

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Compliance with Ethical Standards

Conflict of Interest The authors declare no competing interests.

Ethical Approval The University of Minnesota's Institutional Review Board reviewed the data collection protocols for the project and determined they were exempt from further review.

Informed Consent Informed consent was obtained from all participants included in the study.

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