



Examining Loggers' Attitudes and Behaviors Toward Invasive Forest Plants: A Minnesota Case Study

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ABSTRACT

Logging activities and its associated infrastructure are potential pathways for invasive forest plants, yet little is known about logger activities regarding invasive plants during logging operations. Logging business owners in Minnesota, USA were surveyed about invasive forest plants as a case study to learn about their awareness, interactions with landowners and land managers, actions to control the spread of invasives, perceived business impacts, and information needs. Fifty-one percent of respondents indicated they were either somewhat or very knowledgeable about invasive forest plants in the state, although most were not confident they could correctly identify various plants in the field. Approximately half of the respondents reported voluntarily undertaking activities to prevent the introduction or limit the spread of invasive plants. An association was found between voluntary and contractual invasive plant control activities. While 2% had developed invasive plant treatment expertise as an additional business offering, 51% expressed interest in doing so. Almost 90% were concerned that if additional invasive plant best management practices (BMPs) were to be developed, business impacts would be moderate to large. On their timber sales in the past year, respondents reported that 68% of landowners and 47% of land managers did not discuss invasive plants with them.

KEYWORDS

Timber harvesting; best management practices (BMPs); logging equipment; timber sale contract; plant invasion; training

Introduction

Invasive plants, non-native species that are likely to cause economic or environmental damage, are a pervasive problem in forested ecosystems, with estimates that almost 40% of sampled forested plots in the USA have at least one invasive plant present (Oswalt et al., 2015). Invasive plants are a threat to sustainable forestry in a variety of ways. They aggressively compete with and often displace native forest plant species which alters ecosystem composition (Pyšek et al., 2012), and can adversely impact the health and regeneration of forest lands through reduced forest productivity and altered soil characteristics (Holmes et al., 2009). Additionally, they can negatively impact wildlife habitat suitability and species' abundance, and in turn diminish recreational opportunities, such as hunting, and the provision of other ecosystem services and livelihoods (Eiswerth et al., 2005; Pejchar & Mooney, 2009).

The annual economic impact of invasive plants to natural ecosystems and croplands in the US is substantial, estimated in the billions of dollars (Olson, 2006; Pimentel et al., 2005). Protecting forests from ‘damaging agents’ such as invasive exotic plants is emphasized as a key forest management principle under the Sustainable Forestry Initiative’s (SFI) current forest management standards for sustainable forestry (Sustainable Forestry Initiative, 2015).

Invasive plants are introduced into forested ecosystems through many mechanisms, including purposeful planting for landscaping, erosion control and wildlife habitat improvement (Reichard & White, 2001). Invasive plants can also be accidentally introduced when propagules (e.g., seeds) are carried and deposited by floods or wind events, or from animals, vehicles, and people (Pickering et al., 2010; Rew et al., 2018). Additionally, invasive species can become established or spread as a result of activities that disturb vegetative cover or expose soil, including livestock grazing, fire suppression activities, road building, and recreation (Parks et al., 2005). Logging activities and associated road building are examples of disturbance vectors that can create opportunities for invasive plants to be introduced and spread if seeds of invasive plants become attached to logging and trucking equipment, employee or service vehicles driven to job sites, or boots (Rauschert et al., 2017). Then, if the equipment is not thoroughly cleaned, seeds can be spread and deposited as it is moved between sites (Gavier-Pizarro et al., 2010; Veldman & Putz, 2010). In addition, logging activities can lead to more open canopies and disturbance of soil, which can create conditions conducive to establishment of invasive plants (Setterfield et al., 2005).

Infrastructure has been documented as a key means of invasive species’ spread. Higher concentrations of invasive plants have been correlated with proximity to logging infrastructure (i.e., roads, skid trails, landings) (Buckley et al., 2003; Mortensen et al., 2009; Wangen et al., 2006). While infrastructure is developed in order to access stands for harvesting, it is often used for other purposes after harvest activity is complete. As noted by Dodet and Collet (2012), logging often creates an initial disturbance that has the potential to lead to establishment of invasives, but the associated infrastructure creates corridors and traffic that can accelerate spread by those who continue to use the infrastructure for other purposes. For example, recreationists who utilize the infrastructure (e.g., forest roads and trail corridors) can introduce and spread invasive plants (Anderson et al., 2015; Buckley et al., 2003).

Logging firms generally operate on multiple tracts across the landscape in a given year. For example, Minnesota logging businesses reported harvesting an average of 9.2 timber sales in 2016 (Blinn et al., 2019). Fifty-two percent of the logging business owners responding to that survey (Blinn et al., 2019) traveled 31–60 miles one-way between the respondent’s primary business location and their timber harvest site(s) in 2016 and 74% indicated that the average one-way haul distance from their timber harvest site(s) to their consuming mill(s) was between 31 to 90 miles. Because of their work across multiple timber sales, combined with the distance traveled to harvest sites and mills, loggers have the potential to come into contact with and potentially introduce and spread invasive plants across the landscape.

Timber sale contracts may outline practices for loggers to follow in order to prevent the introduction and spread of invasive plants (e.g., Wisconsin DNR, 2009). For example, on federally owned U.S. Forest Service land, timber sale contracts will identify the location of

known invasive plant infestations and define specific conditions for cleaning logging equipment (USDA Forest Service, 2006). Specifically, logging equipment should be cleaned prior to moving into a cutting area of a Forest Service sale if it was last operating in an area known to contain invasive plants. Equipment must also be cleaned before moving between cutting units of the same sale if operations have occurred in an area with known invasives. Operators are instructed to clean their equipment of seeds, soil, vegetative matter, and other debris that could contain seeds or parts of invasive forest plants. On timber sales within Minnesota Department of Natural Resources (MnDNR)-administered land (state-owned), loggers need to inspect their equipment before entering and leaving a site to ensure that it is free of mud, dirt and reproductive plant parts (MnDNR, 2008). During the timber sale design process, MnDNR foresters attempt to eliminate the need for loggers to apply additional invasive plant mitigation practices by rerouting access, changing the season of operation, or altering the timber sale boundaries to avoid infected areas. The MnDNR also does not require additional mitigation practices if the timber sale is in an area where invasive plants are already present and widespread across the landscape (Personal communication, Doug Tillma, MnDNR Timber Sale Program Supervisor, February 21, 2019). While invasive plants may be identified on the timber sale prospectus on public lands, timber sales on private forest land, particularly family forest lands, are often prepared without the services of a forester (Butler et al., 2016). As such, loggers might be the only professional operating on these sales and lands. Therefore, they may be in a position to point out invasive plants to the landowner and recommend practices to prevent the spread of invasive plants.

We suggest that there are a number of factors which could motivate and influence a logger to discuss invasive plants and/or develop business practices during a timber sale to prevent the introduction or spread of invasives. First, some timber sales have stipulated contractual requirements to undertake equipment inspection and cleaning practices due to invasive plants. Thus, not following contractual guidelines pertaining to invasive forest plants could lead to fines or not being awarded future timber sale contracts. Beyond contractual obligations, though, we suggest that logging businesses might be motivated to discuss and take actions with respect to invasives voluntarily to enhance business opportunities and/or support healthy forest ecosystems. Specifically, logging businesses might be motivated to develop and market invasive plant treatment services as a way to develop a niche set of skills to enhance their business offerings, similar to companies that offer animal-powered logging to capitalize on small-tract and/or low timber volume sales (Toms et al., 2001). Drawing upon business research (Sohn & Lariscy, 2015) and the role of corporate ability and corporate social responsibility in shaping business reputation (Brown & Dacin, 1997), if a landowner or land manager thought that a logger 'infected' their property as a result of logging operations or failed to point out invasives that later became a bigger problem, this could hurt a company's reputation and ability to secure future timber sales. Conversely, being proactive in discussing invasive forest plants with land owners and managers might enhance a company's standing and reputation which could enhance business opportunities. In support of this contention, Khanna (2008) found that companies that voluntarily undertake initiatives to regulate their environmental performance can improve their public image, increase their market share, and charge more for their services. Finally, forest health and health of the logging industry are intertwined (Holmes et al., 2009). We suggest that loggers are innately aware of the

interplay between forest health and health of the logging sector, and because of this, some logging businesses will be motivated to undertake invasive plant inspection and control activities to support sustainable forest ecosystems. In sum, we suggest that logging businesses may undertake a mixture of contractual and voluntary practices to prevent the introduction or control the spread of invasive plants in the course of their harvesting operations, and that these practices are influenced by legal obligations, the potential to leverage business opportunities, and forest health and sustainability concerns. One specific research question that we wanted to explore is whether relationships exist between the pursuit of voluntary and contractual activities by a logging business to control invasive forest plants.

Logging businesses that have operated on public land timber sales in the state have likely been made aware of the issue of invasive forest plants through the practices outlined above for timber sale contracts with known infestations. However, those that operate largely on private land timber sales may have less knowledge and experience with the topic. In spite of the roles that logging businesses and operations could play as both a potential vector and deterrent to the introduction and spread of invasive forest plants, we are not aware of any literature that has examined loggers' awareness, behaviors, and information needs relative to invasive forest plants. To address this information gap, a case study was conducted of logging business owners in Minnesota, USA to gather baseline information about levels of awareness, concern, and current practices. Learning more about these factors will provide information to help inform best management practices and logger training efforts for invasive forest plant management, as well as identify areas of additional research, particularly as they relate to factors that drive actions relative to invasive forest plant control activities.

Methods

A mail survey (Appendix 1) was developed and administered to 359 logging business owners who were Minnesota Logger Education Program (MLEP)¹ members as of spring 2018. The survey questions were worded to indicate that the respondent should consider actions of themselves and their in-woods employees. Thus, the unit of analysis was the logging business. The survey was administered between March 14 and April 27, 2018 by the authors' institution in conjunction with MLEP and the Minnesota Sustainable Forestry Initiative Implementation Committee.

Prior to administration, the survey was reviewed by individuals in the MnDNR and the Minnesota Department of Agriculture for content and clarity. The survey was also pre-tested with two focus groups at the MLEP Logger Conferences held in northern Minnesota during the spring of 2017, and modifications were made to the instrument in response to improve clarity. The final version of the survey contained 29 questions. Following a modified Dillman tailored design method (Dillman, 2000), a total of five contacts were made with potential respondents: a pre-notice postcard, an initial full mailing (i.e., cover letter, questionnaire, postage-paid return envelope), a reminder postcard sent 2 weeks after the initial mailing,

¹MLEP is a private nonprofit educational corporation which provides professional development for Minnesota's logging industry. MLEP membership allows for training as required to meet program standards for agency land and industry certification.

a second full mailing sent to non-respondents 4 weeks after the initial full mailing, and a final letter after the second full mailing to thank respondents and to encourage non-respondents to submit a completed survey. The survey received an exemption from review through the Institutional Review Board of the authors' institution.

Of the 359 surveys that were mailed, 135 responses were received for an overall response rate of 38% and an useable response rate of 37%. To check for nonresponse bias, the initial quartile of respondents was compared to the last quartile following J. S. Armstrong and Overton (1977). Chi-square tests revealed that late responders were slightly more likely to be larger producers (e.g., had harvested at least 15,000 cords of timber volume in the past 12 months) ($\chi^2(1, N = 63) = 5.03, p = .02$), and winter-only harvesting operations ($\chi^2(1, N = 63) = 4.00, p = .05$). However, no significant differences were found between early and late responders relative to their general level of knowledge about invasive forest plants, perceived impacts of invasive plant best management practices (BMPs) on their business operations, level of interest in developing invasive plant treatment or removal expertise, or level of interest in purchasing a timber sale when invasive forest plants are known to be present.

Summary statistics and figures were prepared using Excel, and statistical analyses were conducted with SAS version 9.4. To examine whether there was a relationship between a logging business' decision to undertake invasive plant control activities voluntarily versus contractually, chi-square tests of independence were performed on binary variables created from survey questions which asked whether a respondent had undertaken various activities either contractually or voluntarily in the past 12 months. The activities that were examined included: examining the timber sale site for invasives, inspecting equipment for invasive plants prior to moving it to a different logging site, inspecting equipment for invasive plants prior to removing it from a logging site, and cleaning/washing equipment. Separate chi-square tests were run comparing voluntary versus contractual activity implementation on public land timber sales and similarly on private land timber sales. Eighty percent of the respondents provided responses to open-ended questions. These qualitative data were examined and grouped into major themes. These themes as well as illustrative quotations are presented to amplify and enrich the quantitative findings.

Results

Knowledge of Minnesota's invasive forest plants

Respondents were asked about their general level of knowledge regarding invasive forest plants in Minnesota. Of the 130 responses to this question, the majority of respondents rated themselves as either 'somewhat' knowledgeable (48%) or 'slightly' knowledgeable (40%). Small percentages of respondents rated themselves as either 'very' knowledgeable (3%) or 'not at all' knowledgeable (9%).

To gather information about their knowledge of specific invasive plants, respondents were presented a list of 15 common invasive forest plants in Minnesota, and asked whether they were confident they or their employees could correctly identify them in the woods.² Only 3% of respondents indicated they could not identify any of the 15 plants

²The 15 plants were derived from a management guide that was created using input from various invasive plant specialists within the state (Minnesota SFI Implementation Committee, 2015).

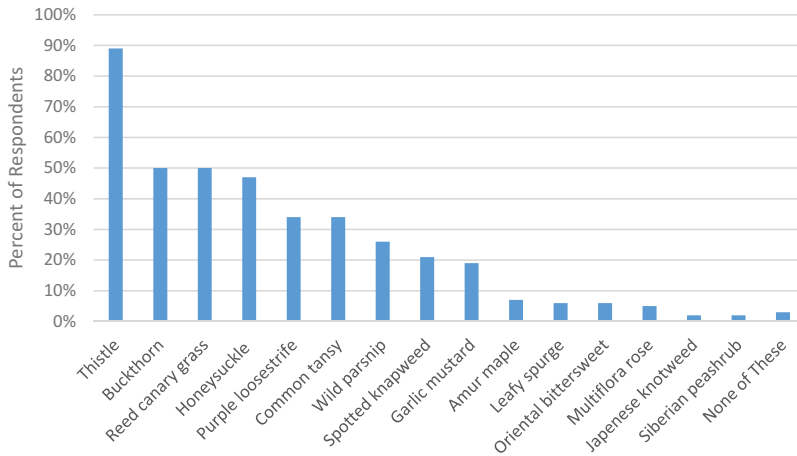


Figure 1. Confidence in the ability of logging business owners or their employees to identify invasive plants in the woods (Percent of respondents) (N = 131).

(Figure 1), while the only plant that a majority of respondents (89%) were confident they could identify was thistle. Approximately half of the respondents could identify three of the plants: buckthorn (50%), reed canary grass (50%), and honeysuckle (47%). The other plants were identifiable by considerably smaller percentages of the respondents. The average number of listed plants that the respondents stated they could identify was 4 (SD = 2.22), and the mode was 2.

Respondents generally did not report high percentages of their sales in the past 12 months having invasive forest plants present.³ Specifically, 20% reported none of their sales and 37% reported between 1% and 25% of their sales had invasive plants, although almost one-third (32%) reported that they did not know (Figure 2).

Current invasive plant control and treatment activities on timber sales

Respondents were asked to consider harvests they had conducted in the past 12 months and indicate the percentage of land owners or managers who had discussed invasive forest plants with them on timber sales. The most frequent response, for both land ownership types, was 0% of owners or managers discussing invasive plants with the logging business (68% for private land timber sales and 47% for public land timber sales) (Figure 3). A small percentage of respondents (4% of private land sales and 16% of public land sales and) reported that invasives were discussed on at least half of their sales in the past 12 months.

A list of activities that logging businesses might undertake to prevent the introduction and/or limit the spread of invasive forest plants was presented, and respondents were asked which, if any, they had been contractually required to undertake in the past 12 months. The list of practices was drawn from the literature (e.g., LeDoux & Martin, 2013) and requirements stipulated on some public land timber sales (e.g., USDA Forest Service,

³The question did not specify the basis a respondent was utilizing to report whether invasive plants were present. They could have responded in the affirmative to this question if invasive plants were mentioned in the timber sale contract or if they independently identified them on sale tracts.

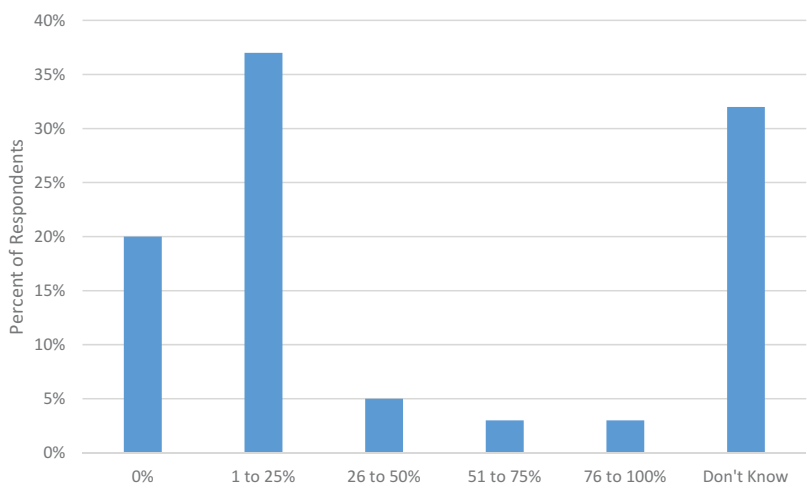


Figure 2. Percent of timber sales in the past 12 months in which the logging business owner indicated that invasive plants were present (Percent of respondents) (N = 130).

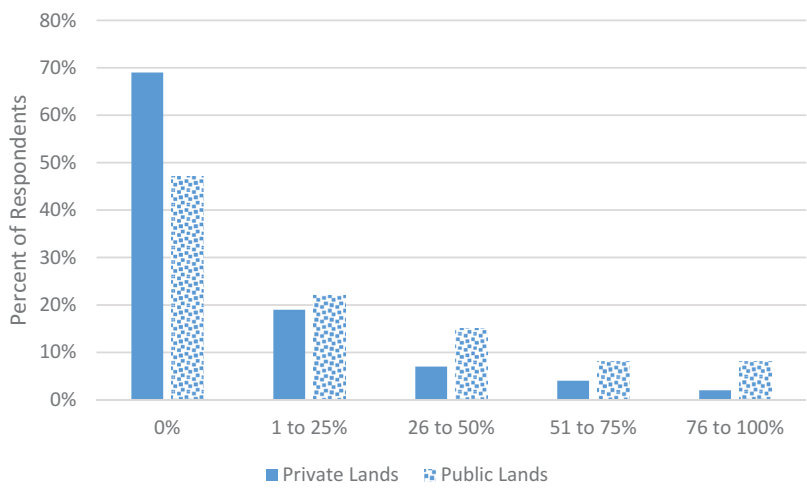


Figure 3. Percent of land owners/managers who had discussed invasive plants with logging business owners or their employees on their timber sales in the past 12 months (Percent of respondents) (N = 100 for private lands and N = 97 for public lands).

2006). More than half of the respondents indicated they had not been contractually required to undertake any of the activities on public land timber sales (61%) or private land timber sales (60%) (Table 1). For three of the activities, approximately one-quarter of the respondents had been contractually required to undertake them on public land timber sales: inspecting equipment for invasives prior to moving it to a different logging site (29%), inspecting equipment for invasives prior to removing it from the job site (26%), or cleaning/washing the equipment (26%). These same three activities were also the three most common contractually required activities on private land timber sales: inspecting equipment for invasives prior to moving it to a different logging site (21%), inspecting

Table 1. Invasive plant control and treatment activities contractually and voluntarily undertaken on timber sales in the previous 12 months (Percent of respondents).

Activity	Contractual activities		Voluntary activities	
	Public sales (N = 95)	Private sales (N = 101)	Public sales (N = 96)	Private sales (N = 103)
Clean/Wash equipment	26%	20%	33%	29%
Inspect equipment prior to removing from job site	26%	20%	35%	32%
Inspect equipment prior to moving to job site	29%	21%	40%	32%
Examine site for invasives	4%	6%	13%	17%
Treat invasives via burning	0%	2%	0%	2%
Treat invasives via herbicide	0%	2%	0%	4%
Manually treat invasives	0%	1%	0%	3%
Mechanically treat invasives	0%	0%	1%	4%
None of the above	61%	60%	45%	47%

equipment for invasives prior to removing it from the job site (20%), and cleaning/washing the equipment (20%). Few respondents (6% for private land sales and 4% for public land sales) reported being contractually required to examine the harvest site for invasives. Of the invasive treatment activities (burning, herbicide application, manual treatment, or mechanical treatment), at most 4% of the respondents reported having to contractually undertake any of these activities on public land timber sales, while at most 6% of respondents reported contractually undertaking any of the treatment activities on private land timber sales.

Respondents were also asked to indicate which of the same eight activities listed in Table 1 they had voluntarily undertaken in the past 12 months in order to prevent the introduction and/or limit the spread of invasive forest plants. Approximately one-half of respondents reported voluntarily undertaking at least one of the activities on either public land timber sales (55%) or private land timber sales (53%) (Table 1). The same three activities undertaken by the greatest percentage of respondents under contractual requirements were also the highest implemented voluntary activities: inspecting equipment for invasives prior to moving it to a different logging site (40% public sales and 32% private sales), inspecting equipment for invasives prior to removing it from the job site (35% public sales and 32% private sales), and cleaning/washing equipment (33% public sales and 29% private sales). The percentages of respondents voluntarily inspecting job sites for invasives were almost triple the percentages of respondents with contractual requirements to do so for each land ownership type. As with the contractual requirements, fewer than 4% of the respondents reported voluntarily undertaking any of the invasives treatment activities (burning, herbicide application, manual treatment, or mechanical treatment).

Chi-squared tests indicated statistically significant relationships at the $p = .05$ level between the implementation of voluntary and contractual invasive control activities on both public and private land sales (Table 2). For example, 100% of the respondents who examined their public land timber sale sites for invasives out of contractual requirements also voluntarily examined their other public land timber sale sites which did not have contractual requirements. Conversely, 92% of respondents who were not contractually obligated to examine their public land timber sale sites for invasives also did not voluntarily examine their public land timber sale sites for invasives. As another example, 90% of respondents who cleaned/washed their

Table 2. Chi-square tests of relationship between contractual and voluntary invasive plant control activities undertaken on timber sales in the previous 12 months (Percent of respondents).

	Examine site for invasives on public land sales		Examine site for invasives on private land sales	
	Voluntarily examine – no	Voluntarily examine – yes	Voluntarily examine – no	Voluntarily examine – yes
Contractually examine – no	92%	8%	89%	11%
Contractually examine – yes	0%	100%	83%	17%
	$\chi^2(1, N = 94) = 31.52, p < .0001$		$\chi^2(1, N = 101) = 23.66, p < .0001$	
	Inspect equipment prior to moving to different logging site on public land sales		Inspect equipment prior to moving to different logging site on private land sales	
	Voluntarily inspect – no	Voluntarily inspect – yes	Voluntarily inspect – no	Voluntarily inspect – yes
Contractually inspect – no	83%	17%	86%	14%
Contractually inspect – yes	18%	82%	12%	88%
	$\chi^2(1, N = 94) = 36.51, p < .0001$		$\chi^2(1, N = 101) = 45.31, p < .0001$	
	Inspect equipment prior to removing it from the logging site on public land sales		Inspect equipment prior to removing it from the logging site on private land sales	
	Voluntarily inspect – no	Voluntarily inspect – yes	Voluntarily inspect – no	Voluntarily inspect – yes
Contractually inspect – no	84%	16%	84%	16%
Contractually inspect – yes	16%	84%	5%	95%
	$\chi^2(1, N = 94) = 37.86, p < .0001$		$\chi^2(1, N = 101) = 46.19, p < .0001$	
	Clean/wash equipment on public land sales		Clean/wash equipment on private land sales	
	Voluntarily clean/wash – no	Voluntarily clean/wash – yes	Voluntarily clean/wash – No	Voluntarily clean/wash – yes
Contractually clean/wash – no	88%	12%	88%	12%
Contractually clean/wash – yes	12%	88%	10%	90%
	$\chi^2(1, N = 94) = 49.30, p < .0001$		$\chi^2(1, N = 101) = 49.41, p < .0001$	

equipment on private land sales due to contractual requirements also voluntarily cleaned/washed their equipment on their other private land sales. Conversely, 88% of the respondents who did not clean/wash their equipment on private land sales because they were not contractually obligated to do so also did not voluntarily clean/wash their equipment on private land timber sales. In sum, respondents tended to undertake the invasive plant inspection and cleaning activities explored in Table 2 either *both* voluntarily and contractually or not at all.

Attitudes toward hypothetical invasive plant BMPs

Respondents were presented a list of 10 potential practices related to invasive forest plant management and asked to rate the difficulty of implementing each. The list of practices was drawn from the literature (e.g., LeDoux & Martin, 2013) and requirements stipulated on some public land timber sales (e.g., USDA Forest Service, 2006). For example, while equipment must be cleaned before entering and leaving an

MnDNR timber harvest site, additional equipment cleaning requirements are only stipulated on the Permit to Cut if the timber sale goes through an infested area that cannot be avoided (Doug Tillma, MnDNR Timber Sales Program Supervisor, Personal Communication, November 29, 2018). Other activities (Figure 4) are not currently required on public timber sales in the state. Response options ranged from ‘very’ difficult (1) to ‘not at all’ difficult (4) on a 4-point scale. The activity that was rated the least difficult to implement was learning to identify invasive plants, with 64% of respondents indicating this practice would either be ‘slightly’ to ‘not at all’ difficult to implement (Figure 4). The practice rated with the greatest difficulty to perform was treatment of staging areas to remove invasive plants prior to bringing in equipment with 59% of respondents indicating it would be a ‘very’ difficult practice to implement. The second-most difficult rated activity was acquiring clean job-site construction materials (e.g., fill dirt, gravel, sand), rated by 50% of respondents as ‘very’ difficult.

Two percent of respondents (N = 124) reported that they have developed invasive forest plant treatment or removal expertise and services as a way to diversify business operations and add additional revenue streams, while only 1% (N = 127) have been hired to provide such services in the past 12 months. When asked how interested they were in developing expertise in invasive forest plant treatment or removal as a way to diversify their operations and potentially add a new revenue stream to their business, 20% were either ‘very’ or ‘somewhat’ interested. However, almost half of the respondents (49%) indicated they were ‘not at all’ interested in developing this expertise (Appendix Figure A1).

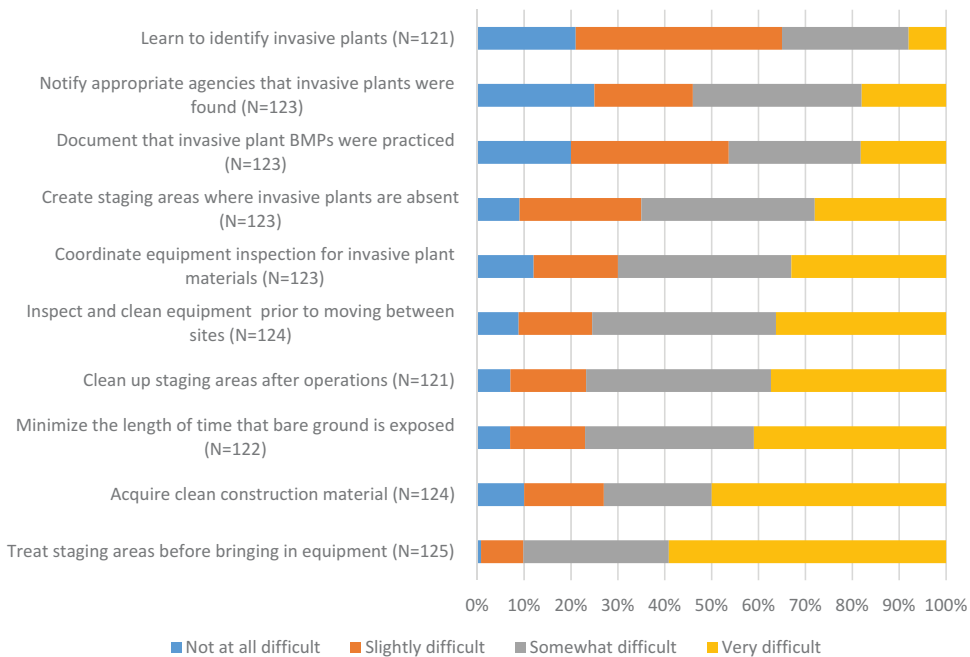


Figure 4. Rating of perceived degree of difficulty to implement potential invasive forest plant BMPs (Percent of respondents) (N varies from 121 to 125).

Business impacts of invasive plants and invasive plant BMPs

Respondents were asked to rate the perceived impact that a hypothetical comprehensive statewide BMP program for invasive forest plants that included the types of activities identified in [Figure 4](#) would have on their logging business. Response options were offered on a 4-point scale ranging from a 'large' impact to 'no' impact. Nearly half (49%) of respondents reported that a comprehensive statewide forest invasives BMP program of this nature would have a 'large' impact on their business, while 13% indicated it would have a 'small' or 'no impact.' (Appendix Figure A2).

Respondents were asked whether they would be less interested in purchasing a timber sale if they knew invasive forest plants are present. Responses were similar across both land ownership types (Appendix Table 1). That is, approximately half of the respondents indicated the presence of invasive plants would not impact their interest in a timber sale, while 30% said that they would be less interested in a sale, and 22% were uncertain.

More than half of the respondents indicated the requirement to undertake invasive plant BMPs would negatively impact their interest in a timber sale (57% of respondents for private land timber sales and 60% for public sales) (Appendix Table 1). Approximately 16% said invasive plant BMPs would not impact their interest in a sale, while approximately 25% were uncertain.

Information and training needs

To learn about their information needs, respondents were presented with nine information/training topics and asked to rank their top three needs relative to invasive forest plants. Only respondents who provided 1st through 3rd rankings were retained. Identification of invasive forest plants was the most frequently cited information need and was rated as the most important training topic by 49% of the respondents (Appendix Figure A3). Business expenses associated with invasive forest plants and logging BMPs associated with invasive plants were cited second and third most frequently, respectively. Only 3% of the total respondents indicated they had no information needs relative to invasive forest plants.

Discussion

Our research provided novel, baseline data about attitudes and business practices of loggers related to invasive forest plants. In addition, our research was the first to examine experience and interest by logging businesses to develop invasive plant treatment activities as a potential new revenue stream. We outline some of the major findings from our survey below.

Lack of awareness or absence?

In general, most respondents report fairly low percentages of their recent timber sales having invasive plants present. Given that data suggest that invasive plants are a pervasive and expanding issue in Minnesota (e.g., Center for Invasive Species and Ecosystem Health, 2018; Kurtz, 2013; University of Minnesota Invasive Terrestrial Plants and Pests Center,

2019), this result raises some important issues. Is the perception that invasive plants are not prevalent on timber sales by Minnesota logging business owners due to a lack of identification of invasive forest plants by timber sale administrators and foresters when preparing the timber sale prospectus? If so, is this because they themselves lack the knowledge to identify the invasive plants and indicate them on the sale prospectus? Or, are timber sale administrators making purposeful decisions to avoid stands with known infestations when offering sales, and/or not addressing identification and treatment in their timber sales even when invasive plants are found? To better answer this question, research is needed that focuses on the level of awareness and identification skills of timber sale administrators and agency foresters, as well as what their operating practices and requirements are regarding invasive plants when writing timber sale descriptions. While avoiding known infested areas when designing timber sales may reduce pathways for further spread of invasives in the short-term, this may not be a sustainable long-term strategy if infestations are not being treated. Additionally, the reported low levels of incidence of invasive plants by our respondents may also be a function of the low levels of confidence in invasive plant identification that the loggers expressed about themselves and their employees. If invasive plants are not identified in the timber sale description and loggers do not have confidence in their ability to identify them, or perhaps incentive to do so, this could explain why respondents were not reporting invasive plants being more commonly present on recent sales in spite of invasive forest plants being prevalent throughout Minnesota (Kurtz, 2013). Moreover, our data illustrate that discussions about invasive forest plants on timber sales between land owners/land managers and logging business owners often do not occur, with almost half of the public land managers and approximately 70% of private landowners not discussing invasive plants with the logging business owner on timber sales in the past year. Efforts to increase communication about invasive plants between land owners/managers and loggers on timber sales could be an important step to enhance awareness and communicate concerns and control methods about invasive forest plants.

The MnDNR makes the largest contribution to harvest levels from public lands in the state (MnDNR, 2017). Because MnDNR foresters use the sale design process to attempt to eliminate the need for loggers to apply additional mitigation practices beyond cleaning their equipment and do not have additional requirements where invasive plants are already present and widespread across the landscape, loggers may not be made aware by foresters of the presence of invasive plants. If the sale design has eliminated the need to operate in an area of concern or the plants are commonly found in the area, they would not be identified within the sale description. Also, as MLEP logging business owners reported that 53% of their volume harvested in 2016 was produced during the winter, invasive plants may be present on their sites but not observed due to snow cover (Blinn et al., 2019).

Current control efforts

Approximately 40% of the respondents report that they have contractually undertaken at least one activity to limit the introduction and spread of invasive plant in the past year, while 50% report having undertaken at least one activity voluntarily. In terms of specific activities, approximately one-quarter of respondents reported either inspecting their

equipment prior to moving in or out of logging sites or cleaning/washing equipment out of contractual obligations. These modest percentages are somewhat surprising given that the MnDNR and the U.S. Forest Service stipulate the need to inspect and clean equipment (MnDNR, 2008; USDA Forest Service, 2006). However, if only small percentages of timber sales in the past 12 months have contained (or identified) invasive plants as indicated by the data in Figure 2, perhaps because of how timber sales have been designed to eliminate areas with invasive plants or due to control activities not being applied in areas where the invasive plants are already so widespread, then limited control practices would be contractually required. Moreover, if harvesting activities occurred during winter months with snow cover when invasive plants might not be visible, loggers may be less motivated or have fewer requirements to undertake invasive plant control actions. Also, some loggers may have institutionalized equipment inspection and cleaning into their normal business practices and do not think of that work as being a contractual requirement.

While our data do not provide evidence of causality or sequencing of activities, they show a relationship between the incidence of contractual and voluntary activities by a logging business to prevent the introduction and spread of invasives. That is, logging businesses either tend to undertake activities like inspecting their equipment for invasive plants prior to moving it both voluntarily and contractually or not at all. Several explanations are possible. Some logging businesses may view invasive plant control activities as good business practices that are beneficial for forest health and sustainability, and may undertake them regardless of whether specific sales contractually require them to do so. Another potential explanation is that once businesses are contractually required to undertake invasives activities, their level of awareness of invasive plants is increased and they in turn could be incorporating such activities as routine business practices and undertaking them voluntarily on other timber sales. Either way, it shows there are some logging businesses who are voluntarily undertaking activities to prevent the introduction and spread of invasives. It would be important to learn more about what is needed to further encourage and assist logging businesses to undertake practices to prevent the introduction and spread of invasive plants, particularly if they are operating in areas with known risk of infestations.

One factor that may impede a logging business' willingness to voluntarily undertake activities to limit the introduction and spread of invasives may be a perception of futility. Specifically, some respondents shared in an open-ended survey question that they felt that once invasive plants are present, requiring them to undertake equipment cleaning and treatment activities relative to invasive plants will be futile and just cost them money and time.

"It is highly improbable that forest practices will make any difference except putting extra burdens on everyone involved."

Thus, training, information and outreach to encourage logging businesses to undertake invasive plant control activities should recognize this perception and its role as a potential impediment and address the need for and effectiveness of different prevention and control activities and business practices.

Whose responsibility?

While logging business owners reported a fair amount of general knowledge about invasive plants, less than a majority of respondents were confident they could identify

most of the 15 common invasive plants included in the survey. Training in invasive plant identification may improve this knowledge gap for loggers and help them serve as early detectors and/or encourage business practices for invasive plant control. This point is reinforced by the response to the question about information and training needs, where identification of invasive plants was the most frequently cited need. Enhancing their knowledge about and ability to identify invasive plants is generally viewed as a reasonable task by loggers given that they rated learning to identify invasive plants as the least difficult of the potential BMPs presented to them in the survey. A training program which combines both indoor classroom with field experiences could meet the needs of most loggers and would mirror the approach used by many logger training organizations nationally (Haworth et al., 2007). Course content could include topics such as the difference between invasive species and a weed or other pest, understanding regulatory options and common practices for controlling invasive species, and use of online tools for identifying and reporting invasive species (e.g., iNaturalist, EDDMapS). Providing training to loggers would also be beneficial in areas where windstorm disturbances have occurred as pre-sale timber appraisals are not typically conducted by foresters in those areas due to the difficulty and/or safety concerns associated with walking through the area following the disturbance (Russell et al., 2017).

Whether it is a function of inability to identify specific invasive plants, knowledge that the timber sale was designed to avoid areas with invasive plants, lack of contractual requirements to do so, or other reasons such as harvesting during winter months when invasive plants may not be visible, most respondents currently are not actively searching for invasives on their timber sale sites. One explanation of these low percentages may be evidenced by a theme that emerged in the open-ended comments, which indicated that respondents felt that public land managers, timber sale administrators, foresters, and/or landowners should be responsible for identifying and undertaking invasive plant treatment and removal activities prior to harvesting on a tract rather than this being a responsibility of the logger.

I figure if the state or county is selling/setting up timber sales with invasive species on the land, then they should help out with things, maybe spraying or killing off before logging starts.

“I own a logging company, not a weed finding and killing company.”

While loggers might prefer to share this responsibility with or give it to timber sale administrators or land managers on public lands, sales on private forest lands are a different matter. Loggers might be the only professionals operating on the private forest land sales and the only ones in a position to identify invasives and/or recommend activities to limit their introduction and spread.

Economic impact

Closely associated with the issue of who should be responsible for identifying and treating invasives was a concern expressed by respondents about the economic impacts to their businesses related to dealing with invasive plants. Almost half of respondents indicated that if they were to be required to undertake invasive plant BMPs, as defined in [Figure 4](#), the impact to their business operations would be large due to implementation costs

incurred as well as the loss of productivity. Various studies have reported increased logging costs and/or reduced productivity due to the implementation of water quality BMPs (Blinn et al., 2001; Kelly et al., 2017; Lickwar et al., 1992; Sawyers et al., 2012; Shaffer et al., 1998). Having experienced those increased costs and reduced productivity associated with implementing water quality BMPs, logging business owners are likely reluctant to want additional BMPs for other issues such as invasive plants.

Further, approximately 60% of respondents indicated they would be less interested in purchasing a sale if invasive BMPs were required. In comparison, the possibility of having to implement invasive plant BMPs has a greater negative influence on interest in a given timber sale than does the presence of invasive plants on the timber sale. The qualitative data provide additional insights into concerns associated with the economic impact of dealing with invasive plants. Specifically, respondents expressed frustration that they were going to bear the economic brunt of more rules and regulations related to invasive plants when they do not feel that they are the major reason for invasives being in the forest.

I fear the bulk of the cost will fall on the logging industry, when in fact we are a small part of the problem.

Any downtime costs money. If markets don't pay for this, then logger will have to. Loggers cannot carry the burden.

The need for financial assistance or questions about who would pay for the additional expense associated with invasive plant prevention or treatment were pervasive in the comments and may represent an impediment to more wide-spread implementation of invasive plant prevention and control activities.

"If we could get paid for identifying and removing invasive plants, I might be more receptive."

Thus, if more expansive invasive plant BMPs were to become formalized or regulated, logging businesses may seek financial assistance or reduced stumpage prices in order to cost-effectively incorporate these business practices. However, it is possible that over time such BMPs might induce efficiency and encourage innovations that help improve competitiveness, as have been found with other practices (Porter & van der Linde, 1995). Those innovations might obviate the need for financial assistance or reduced stumpage prices over time.

It's not just us

Although the survey did not ask any questions about loggers' perceptions about their potential role in invasive plant introduction and spread in Minnesota's forests, many respondents felt strongly about the role of other groups as agents of invasive plant spread. A common theme in the open-ended statements was that other entities and vectors are the major source of invasive plant introduction and spread (i.e., ATV riders, hunters, hikers, birds, wind, flooding, or wildlife). Further, because respondents felt that they are not the primary reason for invasive plants increasing across the landscape, they expressed frustration that they might be singled out to undertake costly measures to further prevent the introduction and spread of invasives.

"Regulate all parties involved in preventing the spread of invasives such as ATV riders, off-road pickups and outdoorsmen."

"Public, ATVs, dogs, etc. are a much bigger problem than loggers,"

Conclusions

A portion of logging business owners are contractually and/or voluntarily undertaking practices to limit the introduction and spread of invasive forest plants in Minnesota which is important for supporting sustainable forestry in the state. Since invasive plant infestations are a landscape-level problem, landscape-level and multi-actor approaches are needed in order to develop effective solutions to such problems. Logging businesses, as well as other groups who work and recreate in forested landscapes, have an important role to play in helping to limit the possibility of introduction and further spread of invasive plants across the landscape. At the same time, logging business owners in our study raised concerns about the impact of having to adopt new business practices and suggested the need for compensation or cost-share assistance to enhance the feasibility and cost-effectiveness for them to adopt those practices. Currently, it does not appear that many of the respondents in our study are motivated to undertake invasive plant control activities by the factors we posited would be influential in the introduction; i.e., an opportunity to offer niche business services or enhance their business reputation as a means to gain market advantages. At this point, respondents' actions and intentions seem to be largely influenced by concerns about economic ramifications of invasive control activities on their business.

One of the keys to a rapid response to invasive plants is the early identification and reporting of new occurrences. Logging business owners may be concerned that if they learn to identify invasive plants and report their presence to a public entity, timber supply may be negatively impacted or the business will be required to perform costly treatments. Thus, remaining "uninformed" of the problem may be their most cost-effective choice.

Given that some respondents indicated they would be less interested in bidding on sales with invasive plants and a majority of respondents would be less interested in bidding on sales with required invasive BMPs, it raises the question as to whether sales with known invasives will be avoided in the future, and if so, whether that would have an impact on a sustainable timber supply and operations in the state.

While respondents generally have not developed skills in invasive plant identification or treatment and removal as an additional business offering, there was some interest in developing these skills among approximately half of the respondents. More work is needed, however, to understand information and training needs, equipment needs, treatment costs, and marketing strategies to help logging businesses interested in developing skills and business offerings related to invasive plant treatment and removal.

Our study is limited by its small sample size of logging business owners in a single state in the northern US. Given this, our results are not likely generalizable to all logging business owners throughout the country, particularly in regions of the country which do not experience periods of snow-cover in which invasive plants might not be visible. Future research that contrasts our findings with invasive plant awareness, concern and control activities of logging businesses in the southern US would be interesting to evaluate whether year-around presence of invasive plants influences awareness and/or activities.

Invasive plants are a landscape-scale issue that require a landscape-scale, multi-actor approach to affect positive change and ensure sustainable forest systems. Loggers are one of the many actors on the forest landscape that have a potential role to play in helping to reduce the further introduction and spread of invasive forest plants through their work practices. Our research was an initial exploration into some of the issues,

challenges, opportunities, and needs that loggers may face in playing a role in invasive plant control.

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