

Current Status and Trends of Silvicultural and Forest Health Practices in Minnesota: A 2017 Assessment

by

M. A. Windmuller-Campione¹, M. B. Russell¹, E. S. Sagor^{1,2}, M. G. Rodman²

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College of Food, Agricultural and Natural Resource Sciences
University of Minnesota
St. Paul, MN

¹ Department of Forest Resources, University of Minnesota; ² Cloquet Forestry Center, University of Minnesota

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

Department of Forest Resources
University of Minnesota
115 Green Hall
1530 Cleveland Avenue North
St. Paul, MN 55108-6112
Phone: 612.624.3400
Fax: 612.625.5212
Email: frweb@umn.edu

Webpage: www.forestry.umn.edu/publications/staff-paper-series

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EXECUTIVE SUMMARY

Silviculture is both an art and a science of how forests regenerate, grow, and are tended through intermediate treatments and final harvests. Silviculture is grounded in applied forest ecology and silvics and is responsive to shifts in values, priorities, technologies, and markets. The silvicultural systems and practices implemented within an individual organization, state, and broader region can give insight into the ways those factors are influencing land management on the ground.

Often the ways these factors influence silvicultural practices represent trade-offs. Within the Great Lakes Region (Minnesota, Wisconsin, and Michigan) in the United States, many different organizations own and manage large holdings of forest land. Each may own and manage the forest land for different goals, with many organizations managing for multiple goals. The use of different silvicultural practices can help elucidate these differences since various techniques can be used to meet distinct goals and objectives.

In Minnesota, there has been an ongoing investment to quantify silvicultural techniques and practices implemented through time. This report represents the most recent output from these investments, as the fourth in a series of reports published between 1991 and the present. This study had two goals; first, to understand current silvicultural practices and forest health priorities and threats and second, to describe and compare broader trends of forest ownership and forest management practices to previous silvicultural surveys completed in 2008, 1996, and 1991.

To achieve these goals, a questionnaire on silvicultural practices and forest health concerns was sent at the end of the calendar year in 2017 to state, county, federal, industrial, non-profit, and tribal ownerships about their forest management practices for their most recent fiscal year. The instrument was developed using fillable PDF software for online completion, but a paper version was offered to any respondents who preferred that format. We did not survey non-industrial private forest landowners or consultants due to lack of response from previous years. Each individual organization was asked to define their fiscal year since the timing of the fiscal year varies by agency. The survey included questions on all parts of the silvicultural system including regeneration, tending, and harvesting, the implementation of best management practices, forest insect and disease issues, and open-ended questions regarding management, missing information, and future needs.

Statewide estimates of timberland area and volume harvested were derived by multiplying the summed totals reported by 2017 respondents by an expansion factor. The expansion factor was calculated as the reported statewide harvest level in 2016 divided by the sum of harvested volume from all respondents, or $2,514,286 \text{ cords} / 1,559,921 \text{ cords} = 1.61$. The statewide harvest volume estimate was provided by the Minnesota Department of Natural Resources based on an annual mill survey. A key assumption we are making is that we can approximate the harvest level for non-respondents and non-surveyed individuals (e.g., private family non-industrial forest landowners) from harvest leveled acquired in our survey. Due to changes in both the survey

methods and the wording of questions from the previous surveys, we have focused on the general trends without statistical comparisons.

We distributed the survey via email to 29 forest resource land owners in the state (15 county, 2 national, 1 state, 2 non-profit, 4 forest industry, and 5 tribal organizations). Twenty-two organizations responded; a response rate of 76%. Survey respondents included state, federal, county, industrial, tribal, and non-profit agencies that collectively own 10,367,761 million acres of forest land across Minnesota. This group includes 66% of the 15.82 million acres of timberland in Minnesota. Individual respondent ownerships ranged from a few thousand to a few million acres.

Respondents reported selling 1,548 timber sales during the study period. Federal, industrial, and non-profit organizations reported all sales offered were sold. The total statewide harvest volume was estimated at 2,514,286 cd, down about 14% from the statewide estimate of 2,924,500 cd reported in 2008. The continued reduction in harvest levels since 1996 likely reflects the slow and incomplete recovery of the housing market first reflected in the 2008 report and the reduction in mill capacity with numerous sawmills and one pulp mill closing between 2010 and 2014 (Walters et al. 2016, Walters et al. 2018).

Respondents reported harvest activity on a total of 90,515 acres in 2017, suggesting a statewide harvest area estimate of 145,894 acres assuming harvest activity on non-surveyed timberlands are similar to harvest activity on surveyed lands. Both figures are higher than those reported for 2008 (88,965 ac and 134,209 ac, respectively) but lower than the corresponding figures from the 1996 and 1991 reports.

With a higher reported harvest area and lower harvested volume than in 2008, we see a continued decline in harvest intensity, reported as the average volume harvested per timberland acre. In 2017 this figure is estimated as 0.15 cd/ac, compared to 0.20 cd/ac in 2008 and 0.26 cd/ac in 1996. This reduction in per-acre harvest volume may reflect a large blowdown that occurred across central and northern Minnesota during the previous fiscal year, impacting the harvesting levels and silvicultural practices. It may also be due to the age class structure of one of Minnesota's dominant forest types, aspen, and the loss of volume in some older stands.

The clearcut silvicultural system was still the predominant regeneration harvest among most land management organizations. Based on a reported total clearcut area of 65,607 acres, we estimated a statewide total clearcut area of 105,746 acres. Based on these figures, about 72% of the total harvest area was harvested using a clearcut system in 2017. This percentage was well below the high of 91% of harvested acreage in 1991 and continues a steady decline in the percentage of harvested acreage that was clearcut. The average clearcut size in 2017 was 17 acres, substantially lower than 2008 (29 ac) or 1996 (24 ac) (Table 1). In summary, in 2017, timber harvests occurred on more acres but at a lower intensity than in 2008.

Other regeneration harvests (strip clearcut, seed tree, shelterwood, and group and single-tree selection) totaled 11% or 9,643 acres harvested by respondents during the survey period, producing a statewide estimated total of 15,543 acres. Two of these "other" regeneration harvest

types are designed to produce uneven-aged stands: group and single-tree selection harvests. These harvests (or partial harvests from previous reports) are estimated to account for 5.8% of the total harvest area, or 5,276 acres (8,504 ac statewide). All ownership groups used uneven-aged management in 2017. The 11% total harvest acreage in other even-aged systems and uneven-aged systems is slightly higher than 2008 (8%) and much higher than 1996 (3%) and 1991 (2%). This represents a continued shift toward increasing complexity of multiple silvicultural systems utilized across Minnesota's managed forest land.

Not all harvests are designed to produce regeneration. Thinnings accounted for an estimated 17% of the total harvested acreage, or 15,266 acres by respondents (24,606 ac statewide). As a percentage of the total harvest area, this is the highest figure of the four reports dating back to 1991 (Table 2). On an area basis however, the total thinned acreage reported by respondents in 2017 is lower than 2008 (17,809 ac) but substantially higher than 1996 (10,602 ac) or 1991 (5,408 ac).

Post-harvest regeneration activities including under planting, utilizing natural regeneration, and other regeneration methods occurred on 74,180 acres of forest land as reported by respondents, leading to a statewide estimate of 119,564 acres in 2017. The statewide total acreage regenerated is relatively consistent across survey years with 130,257 acres in 2008, 166,380 acres in 1996, and 161,400 acres in 1991. To summarize total harvest activity in 2017, 72% of harvests were in clearcut silvicultural systems, 11% of harvests were in other even- and uneven-aged systems, and 17% of harvests were in commercial thinnings.

Thirteen tree species were identified by survey respondents as difficult to regenerate. The top three species were jack pine (n=8), eastern white pine (n=7), and northern white cedar (n=6). Difficulty regenerating some of these species may be due to herbivory. In 2017, respondents reported that 27,265 acres (n=21) were protected from herbivory. This should be viewed as a minimum since not all respondents reported or reported difficulties in accurately assessing this number. The majority of the reported acreage (20,296 ac) was protected using bud capping. The impacts of herbivory have been highlighted within several goals of the state's Deer Management Plan, with an emphasis on exploring monitoring efforts to assess browse impacts on native vegetation.

All ownership groups did some level of site preparation, timber stand improvement, and intermediate treatments in 2017. Respondents reported site preparation treatments on 8,689 acres and timber stand improvement (TSI) treatments on 9,525 acres in 2017. Both figures are lower than the corresponding acreages treated in 2008 and 1996, suggesting a reduced investment in site preparation and intermediate treatments in 2017. This reduction may be due again to the type of harvesting occurring after a large blow down event.

The 2017 survey reduced the number of questions related to biofuels and biomass harvesting and increased the number of questions related to forest health. Total acreage harvested for biofuels was consistent between 2008 and 2017; there were 7,592 acres harvested in 2017 and 7,642 acres in 2008. The two biggest forest health threats identified through the 2017 survey were emerald ash borer (n=9) and eastern larch beetle (n=5). All respondents who completed the question on

windthrow/blowdown had been impacted by this disturbance, which highlights the prevalence of wind as a disturbance agent in Minnesota. Multiple silvicultural treatments were being used for these forest health threats and others threats identified in the survey including salvage harvests, the promotion of mixed species stands, and thinning to reduce density and increasing resilience.

There continued to be changes in forest management and silvicultural practices. Just over half of respondents in 2017 identified that their silvicultural practices have changed over the past 5 years (n=11 for change, n=9 for no change). The main changes that organizations implemented were using different silvicultural systems (n=3), increasing harvesting intensity (n=2), and shifting politics (n=2).

There was also a 50/50 (n=20) split among organizations in perceptions of the ease of implementing Minnesota's Forest Management Guidelines. The two most challenging guidelines to implement related to leave tree retention (n=5) and biomass utilization (n=3). Respondents also noted that guidelines related to harvest infrastructure, soil compaction, and riparian management zones (RMZs) contributed to difficulty in implementation. As additional information, research, and on-the-ground practices are shared across the forestry community in Minnesota, these difficulties in implementation for some Guidelines (e.g., leave tree retention) may continue to decrease. However, changing conditions may increase the difficulties of others like soil compaction. This may become an increasing concern since the majority of volume in Minnesota is harvested during the winter. Surveys to logging business owners in 2011 and 2016 identified 51% and 56% of volume, respectively, was harvested during the winter season (Blinn et al. 2014, Blinn et al. 2019). Changing winter conditions and also assessing the trade-offs of harvesting on non-frozen ground may impact the ability of organizations to meet site level guidelines for soil compaction.

There continue to be distinct differences in silvicultural practices utilized by different forest management organizational groups. The ordination of ownership practices and trends continues to display distinct differences related to ownership size, types of silvicultural systems used, and types of intermediate treatments (chemical versus mechanical). An additional important note is that no ownership group was static and practices continue to change over time. We expect forest management practices to continue to evolve and adapt to current and future challenges. The investment in documenting these trends and treatments across time provides important knowledge and insight into forest management across the different ownerships in Minnesota.

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1. INTRODUCTION

Silvicultural systems and practices represent a balance in the foundation of silvics and forest ecology and the need to manage for a landowners goals and values. The theme of balance is central to the discipline of silviculture as the definition explicitly accounts for both science and art with silvicultural prescription developed based on various goals and values (Helms 1998; Nyland 2016). This allows one to gain insight into the broader goals and values within a region, forest type, and/or agency based on the type of silvicultural systems used. As with many aspects including forest management, overarching goals and values are not static but can change and evolve over time (Puettmann et al. 2012). There has been investment in Minnesota to understand how goals, values, and broader impacts (e.g., invasive species, disturbance, forest management guidelines) influence silvicultural practices, acreage harvested, and stumpage prices over the last 26 years (Jaako-Poyry 1992; Puettmann et al. 1998; Puettmann and Ek 1999; D'Amato et al. 2009).

Silvicultural treatments are the primary means by which forest managers achieve objectives and implement forest management activities which are related to the values and mission of public agencies, private companies, and even the private individuals or families that own Minnesota's approximately 17 million ac of forest land (Miles et al. 2017). The relative importance of priorities like various forms of forest-based recreation, rural land development or land-use conversion including from forest to cropland, and forest health are continually changing.

Exogenous forces such as a changing climate, the introduction of new invasive species, and variability in market forces also influence silvicultural treatments at both a site- and landscape scale. There have been changes from the last silvicultural survey (D'Amato et al. 2009). This includes changes in Minnesota's mill capacity with the most recent shut down of machine #5 at UPM Blandin Mill in the Fall 2017 (Anonymous, 2017). Since the last silvicultural survey, there has been a loss of mill capacity (Walters et al. 2016, Walters et al. 2018). However, other factors are likely to increase the statewide timber harvest level. In March 2018, the State of Minnesota, which manages 5.8 million acres of forest land, completed a Sustainable Timber Harvest Analysis that recommended a target harvest level of 870,000 cd/yr on state managed lands, supplemented for five years with an additional 30,000 cd from species under imminent threat (Stander et al. 2018). This new target harvest level represents an increase from recent annual harvest levels of approximately 800,000 cd/yr.

Through the Minnesota Department of Natural Resources (DNR) Division of Forestry, the State has also expanded the capacity of its Private Forest Management program, through which its staff advise private woodland owners on the management of their lands, which collectively total almost $\frac{1}{3}$ of Minnesota's forest. Additionally, timber sales on federal lands using the Good Neighbor Authority have been widely and successfully implemented in the neighboring state of Wisconsin and thus can be predicted that this tool will be utilized more in Minnesota.

At the same time, the presence and importance of plant and insect invasive species are expanding across Minnesota, with emerald ash borer (EAB) now documented not only in southern

Minnesota since 2009, but more recently in the Duluth-Superior metropolitan area and in Winnipeg, Manitoba, suggesting the possibility of introduction across northern Minnesota (Minnesota Department of Agriculture 2018, Kolka et al. 2018). Other invasive insects, including the native eastern larch beetle (ELB), have had outbreaks unprecedented in scale and duration across northern Minnesota in recent years driven by what appears to be a climate-related change in life cycle leading to rapid population expansion (McKee & Aukema 2015, Crocker et al. 2016). The DNR Sustainable Timber Harvest Analysis will focus on increasing harvesting in both the ash forest types to proactively manage for EAB and the eastern larch forest type. An additional threat to our pine forest types is the potential introduction or natural spread of mountain pine beetle (Windmuller-Campione 2017). Mountain pine beetle has expanded outside of its historic range and is currently observed, reproducing, and causing mortality in southwestern Saskatchewan (Cypress Hills). In addition, invasive plant species such as buckthorn, tansy, and knapweeds are widespread across the state and may inhibit tree regeneration. There is increased concern from natural resource managers on how current and future invasive species will impact numerous forest types in Minnesota.

Much of Minnesota's timberland occurs on soils that are more susceptible to compaction and is thus accessible only during frozen-ground conditions. Even on uplands, concern about soil compaction, erosion, and sedimentation of water bodies can limit the ability to implement desired silvicultural treatments across much of the land base (MFRC 2013). This problem may be exacerbated as the duration of Minnesota's frozen-ground season may be shrinking (MN Department of Health 2015). Unfortunately this will likely disproportionately affect species like black ash and eastern larch that predominantly colonize wet forest conditions and are threatened by EAB and ELB (D'Amato et al. 2018). Past Minnesota silvicultural surveys have indicated that up to 58% of Minnesota's annual timber harvest occurs during frozen-ground conditions (D'Amato et al. 2009), making winter access important to land managers' ability to implement desired treatments.

While the particular changes and conditions facing Minnesota forests and forest landowners today may be unique, changes in forest composition, markets and economic factors, and of course the values and priorities of landowners have been continual changing. This continual change makes longitudinal studies of silvicultural practices in the state all the more important to document the ways that those changes are reflected in the landscape. Long-term studies can also inform our understanding of the degree to which landowners are responding, proactively or reactively, to the changes they are facing.

This study is the fourth in a series of Minnesota state silviculture surveys, with previous reports describing practices dating back to 1991 (Jaako-Poyry 1992) and including the years 1996 (Puettmann et al. 1998), 2001 (Puettmann and Ek 2002) and 2008 (D'Amato et al. 2009).

2. OBJECTIVES

There were three main objectives for this work:

1. To understand the implementation of current silvicultural practices and how important drivers such as forest health and markets (biomass) influence decisions,
2. To compare current silvicultural practices to previous surveys in 2008, 1996, and 1991, and
3. To assess current and predicted future opportunities and challenges in silvicultural practices.

3. METHODS

3.1. QUESTIONNAIRE

In the fall of 2017, a questionnaire on silvicultural and forest management practices using respondents' most recent fiscal year was developed, approved by the Institutional Review Board at the University of Minnesota, and administered (Appendix A). The fiscal year was left to be defined by the individual respondent for each organization to allow respondents to more easily gather data and report on silvicultural treatments that are recorded by fiscal year in their databases.

The survey questions followed a similar pattern and subject matter as previous surveys to maintain consistency and allow for comparisons across years. However, some previous questions were removed including detailed questions regarding biofuels due to changing markets. Additional questions were added on invasive species and management related to forest health. The survey consisted of seven sections including (1) annual forest management operations, (2) silvicultural activities, (3) biofuels harvests, (4) regeneration methods, (5) site preparation methods, (6) forest health, and open-ended questions on (7) trends in silvicultural practices. Prior to the formal distribution of the survey, a draft was reviewed by key forest managers in state, county, and private organizations, as well as colleagues within the University. Based on comments from those reviews, revisions were made to the survey to assure clarity.

The survey was administered following Dillman (2000) method and was conducted through a fillable PDF form which allowed respondents to complete the survey either by hand or digitally. We distributed the survey (Appendix A) via email to 29 forest resource land owners in the state (15 county, 2 national, 1 state, 2 non-profit, 4 forest industry, and 5 tribal organizations). As we solicited responses from major land owners and land management agencies, the 29 organizations made up a large proportion of the timberland in Minnesota. We obtained contact information for respondents from databases maintained by the Sustainable Forests Education Cooperative and from publicly-available directories of county, state, and federal employees.

Two days prior to distributing the survey we sent an initial email letter to each recipient requesting their participation (Appendix B). The email described the purpose, funding source, and importance of high participation rates for the study. On November 9, 2017 we distributed the fillable PDF survey, a glossary of terms used in the survey (Appendix C), and a second letter via email to all 29 recipients. The email described the voluntary nature of the survey and general nature of the questions. This email also informed participants that submitted data would be kept confidential and provided contact information for the University of Minnesota Research Participants' Advocate Line.

We tracked respondents' survey completion to facilitate follow-up emails, mailings, and phone calls. We sent a follow-up email and postcard to all nonrespondents approximately four and five weeks, respectively, after the initial distribution of the survey. After the December 31, 2017 submission deadline had passed we sent an additional inquiry email and made phone calls to remaining nonrespondents. Due to the cold winter of 2017-2018 allowing for increased silvicultural activities, we extended our submission window for survey data into the summer of 2018. Ultimately, this extension allowed an additional three large landholding respondents to complete the survey.

3.2. SURVEY ANALYSIS

Due to changes in both the survey methods and the wording of questions from the previous surveys, we have focused on the general trends without statistical comparisons. There is still great value in the trends and comparison across years. Nonmetric multidimensional scaling (NMS) ordination was used to explore general trends and patterns in silvicultural practices across time and among different ownership within Minnesota. The NMS ordination used data that was collected across the survey years and was analyzed in PC-ORD version 6.

Statewide estimates of timberland area and volume harvested were derived by multiplying the respondent silvicultural system acreages by an expansion factor based on the reported statewide harvest level in 2016 divided by the sum of the respondent reported harvests. This approach expanded respondent acreages in silvicultural systems using an expansion factor based on the reported statewide harvest levels divided by the respondent reported harvests (i.e., $2,514,286 \text{ cords} / 1,559,921 \text{ cords} = 1.61$). A key assumption we are making is that we can approximate the harvest level for non-respondents and non-surveyed individuals (private family non-industrial forest landowners) from harvest leveled acquired in our survey. The statewide harvest level used was an estimate, as final mill survey numbers had not been received at the completion of our study. Preliminary harvest level estimates were provided by Scott Hillard, MN Department of Natural Resources.

4. RESULTS AND DISCUSSION

The general outline results and discussion will follow a similar format to previous reports to allow for ease of comparison among reports.

Twenty-two forest management agencies representing approximately 10.4 million acres of forest land across Minnesota responded to the survey. These respondents represented state, federal, county, forest industry, tribal, and non-profit agencies. While, the level of participation was slightly lower than previous surveys (with 26 respondents in 2008 and 25 respondents in 1996), the 2017 survey represented slightly more timberland than previous surveys (Table 1).

Participation in 2017 may have been lower due to a few factors: changes in organizations managing timber (one organization was no longer actively managing timber), turn-over in the workforce (two agencies reported being extremely short staffed), and weather conditions (the winter of 2017-2018 was the first cold winter in two years). While, participation may have been slightly lower, we captured the vast majority of the timberland base in Minnesota. We did not survey non-industrial private forest consults due to lack of response from previous years.

The respondent ownership covered a total of 10,367,761 acres of timberland (Table 1). Individual respondent ownership ranged from a few thousand acres to several million acres. Total reported acreage in our survey was 66% of the 15.82 million acres of timberland in Minnesota (Miles et al. 2017). Respondents reported successfully selling 1,548 timber sales with federal, forest industry, and non-profit ownerships reporting all sales offered were sold. County (2.3%), state (14.3%), and tribal ownerships (15.8%) had an additional 156 sales that were not sold. Statewide estimates of harvested volume across all ownerships was 2.51 million cords (Table 1), which was lower than reported harvest volume in 2008 (2.92 million cords) and still well below the 3.81 million cords reported in 1996 (Figure 1). As reported in the 2008 report, the slightly lower harvest level likely represented the slower recovery of the housing market and the reduction in certain paper markets. Additionally, we saw a continued decline with lower harvest volume per acre in 2017 (0.15 cords/ac) compared to 0.20 cords/acre in 2008 and 0.25 cords/acre in 1996 (Table 1). This lower harvest volume may be fueled by a large blowdown that occurred across central and northern Minnesota during the previous fiscal year, impacting the harvesting levels and silvicultural practices (see sections below for additional discussion).

4.1. SILVICULTURAL SYSTEMS

The clearcut silvicultural system was still the predominant regeneration harvest among most land management organizations. Based on a reported total clearcut area of 65,607 acres, we estimate an annual statewide total clearcut area of 105,746 acres. Based on these figures, about 72% of the total harvest area was harvested using a clearcut system in 2017. This percentage was well below the high of 91% of harvested acreage in 1991 and continues a steady decline in the percentage of harvested acreage that was clearcut (Figure 2). The average clearcut size in 2017 was 17 acres, substantially lower than 2008 (29 ac) or 1996 (24 ac) (Table 2).

All organizational groups used the clearcut system in 2017 (Table 3). Forest industry had the largest percentage of harvested acres in the clearcut system and federal ownership the lowest at 78% and 42%, respectively. We did not ask respondents to group clearcut harvests based on the size of the harvest due to feedback from previous surveys.

Other regeneration harvests (strip clearcut, seed tree, shelterwood, and group and single-tree selection) totaled 11% or 9,643 acres harvested by respondents during the survey period, producing a statewide estimate of 15,543 acres. Two of these “other” regeneration harvest types are designed to produce uneven-aged stands: group and single-tree selection harvests. These harvests (or partial harvests from previous reports) are estimated to account for 5.8% of the total harvest area, or 5,276 acres (8,504 ac statewide). All ownership groups used uneven-aged management in 2017.

The percentage of the total harvest acreage in other even-aged systems and uneven-aged systems are slightly higher than 2008 (8%) and much higher than 1996 (3%) and 1991 (2%). This represents a continued shift toward increasing complexity of multiple silvicultural systems utilized across Minnesota’s managed forest land.

Not all harvests are designed to produce regeneration. Thinnings accounted for an estimated 17% of the total harvested acreage, or 15,266 acres by respondents (24,606 ac statewide). As a percentage of the total harvest area, this is the highest figure of the four reports dating back to 1991 (Table 2; Figure 2). On an area basis however, the total acreage reported thinned by respondents in 2017 is lower than 2008 (17,809 ac) but substantially higher than 1996 (10,602 ac) or 1991 (5,408 ac). To summarize total harvest activity in 2017, 72% of harvests were in a clearcut silvicultural systems, 11% of harvests were in other even- and uneven-aged systems, and 17% of harvests were in commercial thinnings.

4.2. REGENERATION

Post-harvest regeneration activities occurred on 74,180 acres of forest land as reported by respondents, leading to a statewide estimate of 119,564 acres in 2017 (Table 3). The statewide total acreage regenerated is relatively consistent across survey years with 130,257 acres in 2008, 166,380 acres in 1996, and 161,400 acres in 1991.

On average just under two-thirds (64%) of this regeneration was hardwood species including aspen, with the remaining 36% in conifer species (Table 4). State ownership had the highest percentage of hardwood regeneration 87% (13% conifer) and non-profit had the lowest, 42% (58% conifer). This categorization of conifer versus hardwood regeneration was a new question this year. Prior to this year’s lower figure, the total acreage regenerated by respondents has been relatively consistent across survey years with 95,167 acres in 2008, 88,100 acres in 1996, and 84,991 acres in 1991. This consistency in regeneration level represents a continued investment in sound silvicultural practices.

Multiple regeneration methods were used across organizations including underplanting (4,461 ac), direct seeding (3,759 ac), natural regeneration from sprouts (48,907 ac), and natural

regeneration from seed (10,776 ac)(Table 4). No respondents reported using cuttings as a regeneration method during the 2017 survey year. A total of 897 acres were replanted from a previous year. This should be viewed as a minimum since multiple organizations reported difficulty tracking replanting numbers.

However, level of replanting should not be surprising since a total of 27,265 acres from 21 respondents were protected from herbivory (Table 4). The main tool used to protect seedlings was bud capping at 20,296 total acres. All organizational groups reported bud capping. Other herbivory protection techniques included cages around individual trees (541 ac), large fences (9 ac), sprays or repellents (253 ac), hand release (6,164 ac), and small exclosures around a few trees (2 ac). Herbivory questions are new to the 2017 survey and were added based on comments regarding impacts from herbivory in previous surveys and other discussions with natural resource managers. The impacts of herbivory have been highlighted within several goals of the state's Deer Management Plan, with an emphasis on exploring monitoring efforts to assess browse impacts on native vegetation (MN DNR 2018).

Thirteen tree species were identified as difficult to regenerate by forest management organizations (Figure 3). Organizations could identify more than one tree species in the survey. Three conifers were listed as the most difficult, including jack pine (n=8), eastern white pine (n=7), and northern white cedar (n=6). Paper birch and northern red oak followed next with 5 respondents. High difficulty regenerating eastern white pine and northern white cedar are consistent with decades of research - high deer levels, disease issues in eastern white pine, and also historic management practices removing seed source, all contribute to difficulties regenerating the species (Cornett et al. 2000, Rooney et al. 2002, White 2012, and many others). It is maybe more surprising that jack pine was rated highest especially since it was not too distant when jack pine was selectively removed from pine stands, to promote red pine. This shift toward increasing jack pine dominance on the landscape may be related to managers wanting to increase species diversity in pine stands and/or restore pine barrens (Handler et al. 2017). However, with the removal of fire as a disturbance agent, regenerating jack pine through natural or artificial regeneration may require testing of different site preparation tools.

4.4. SITE PREPARATION, TIMBER STAND IMPROVEMENT, & INTERMEDIATE TREATMENTS

Respondents reported site preparation treatments on 8,689 acres and timber stand improvement (TSI) treatments on 9,525 acres in 2017 (Table 4). Both figures are lower than the corresponding acreages treated in 2008 and 1996, suggesting a reduced investment in intermediate treatments in 2017. This reduction in intermediate treatment may be due in part to organizations responding to the large blow down event.

All organizational groups did some level of site preparation, timber stand improvement, and intermediate treatments in 2017. There has been a continued decrease in site preparation since 1991 where there was a high of 15,206 acres; in 1996 and 2008 site preparation occurred on 12,950 acres and 12,632 acres, respectively. Mechanical treatments have been the most common method across all survey years; in 2017, 70% (6,026 ac) were treated through mechanical

methods. Aerial spraying of chemicals was the least common (17 ac on state land). Prescribed burning remains a little-used site preparation technique, with only 351 acres reported across all organizational ownerships and no acres reported by county or nonprofit owners. However, this number may increase in future years with increased interest from multiple organizations and recent workshops hosted by Sustainable Forests Education Cooperative and Lake States Joint Fire Science Program at the Cloquet Forestry Center.

Timber stand improvement (TSI) occurred on 8,689 acres in 2017. This is roughly half the acreage treated in 2008 and 1996. Mechanical treatments were the most common in 2017 and were implemented on 5,151 acres (54%); treatments were roughly split among three organizational groups: county (1,619 ac), federal (1,880 ac), and forest industry (1,507 ac). The second most common method in 2017 for TSI was ground-based chemicals (2,604 ac); all organizational groups used ground-based chemical except for federal ownerships. Pre-commercial thinning was relatively stable from 2008 with 1,023 acres treated in 2017 and 1,444 acres treated in 2008; this was lower than the 3,055 acres treated in 1996. Commercial thinning occurred on 15,266 acres across all ownerships in 2017. State ownership had the most acres treated by thinning (3,690 ac) and federal ownership had the highest percentage (30%). Commercial thinning (15,266 ac) was relatively stable from 2008 (17,740 ac) and was greater than the 10,602 ac treated in 1996. The relative stability of both pre-commercial and commercial thinning from 2008 to 2017 compared to 1996 may represent a continued shift to mechanized thinning, including cut-to-length (CTL) operations.

Salvage operations saw a large increase in 2017 with 5,852 acres reported harvested compared to 210 ac in 2008. In 2017, all organizational groups had salvage operations except for federal and non-profit organizations. A few respondents in the survey noted this increase in salvage harvests due to a severe blowdown in 2016 resulting in a change to their harvesting plans for fiscal year 2017.

4.4. BIOMASS & SLASH DISPOSAL

In the 2017 survey, slash disposal was only addressed in the context of biomass harvest. These series of questions were removed due to previous comments regarding the length and complexity of the survey. Numbers regarding slash disposal not related to biomass can be found in Table 5 and greater discussion in previous reports.

Total acreage harvested for biofuels was consistent across the two survey years, 2008 and 2017; there were 7,592 acres harvested in 2017 and 7,642 acres in 2008 (Table 5). Just over half of respondents (n=20) to the questions in 2017 reported some level of biomass harvesting. Since the averages reported for total in 2017 include 0's from those respondents not harvesting, we see a lower average percentage of biofuels removed on second harvest (3.3%) compared to 21% in 2008. There was an increase in biofuels harvested as roundwood and sold as biofuels in 2017 (26%) compared to 2008 (20%). Slash disposal prior to collection was more evenly distributed in 2017 compared to 2008. In 2017, 23% of slash was piled at landings, 25% was scattered, and 37% were in other locations (a new survey response added in 2017). In 2008, 75% of slash was piled at landings and 3% were scattered. There was also an overall decrease in the average

percent of sub-merchantable material being harvested and hard snags harvested in 2017 compared to 2008. The highest harvest percent of biofuel sub-merchantable material use was 95% for non-profit organizations with most other organizational groups around 40%. Organizational groups in 2008 had higher average percentages for submerchantable harvesting, around 70%. The decrease in hard snags harvested may be a result of the MN Best Management Practices and the recognition of standing snags for numerous wildlife species.

4.5. FOREST HEALTH

In response to the question “Which of the forest health issues listed in the tables in section 6 is your biggest threat?”, emerald ash borer was identified by 43% of respondents ($n = 9$), the largest of any forest health threat (Figure 5). Eastern larch beetle ranked the second biggest forest health threat ($n = 5$; 24% of respondents) while spruce budworm, white pine blister rust, and windthrow/blowdown all ranked third with 10% of respondents ($n = 2$) indicating these issues were their biggest forest health threats. The finding that EAB was the single largest forest health threat identified in this survey is likely in response to increased understanding of the extent and abundance of ash in Minnesota in addition to the finding of EAB in Duluth, MN in 2015, representing the first known EAB report in an area north of the Twin Cities Metro region.

Windthrow/blowdown occurred on all organizations lands who responded to the question, which highlights the prevalence of this disturbance agent in Minnesota (Figure 6). Similarly, just 5% of respondents indicated white pine blister rust and forest tent caterpillar were not known to occur on their land. This may be a reflection of how widespread the geographic ranges are for these host species in Minnesota, i.e., eastern white pine for blister rust and a broad suite of hardwoods including aspen, birch, and oaks in the case of forest tent caterpillar. On the contrary, oak wilt (64% of respondents), gypsy moth (59% of respondents), and EAB (50% of respondents) were the three forest health threats that respondents indicated were not known to occur on their forests. Although there are a large number of species and forests that are susceptible to these agents, the finding that these threats were not known to occur is likely due to their limited geographic range in Minnesota as of 2017. While forest tent caterpillar and eastern spruce dwarf mistletoe were present on many forests, (82% and 55% of respondents, respectively), forest managers indicated these threats were present but were not taking actions to treat them (Figure 7).

Respondents implemented various silvicultural practices to manage forest health threats (Figures 8-10). Clearcutting was commonly used to treat forest health issues related to aspen and birch species, including the presence of hypoxylon and aspen/birch decline (50% and 36% of respondents, respectively). Sixty-eight percent of respondents indicated using salvage harvests following windthrow/blowdown events. Salvage harvesting was also implemented as a silvicultural practice in response to two insect agents: the eastern larch beetle and spruce budworm (32% of respondents for both insects). For intermediate stand treatments, 46% and 14% of respondents indicated using pruning as a common practice for white pine blister rust and white pine weevil, respectively. Thinning methods were commonly used to combat problems with bark beetles, as indicated by 45% of respondents.

Forest managers highlighted promoting mixed-species as a method to combat many forest health threats, most notably for EAB (27% of respondents). Improved growing stock was mentioned as a treatment for managing white pine blister rust and *Diplodia* and *Sirococcus* shoot blights for 18% and 9% percent of respondents, respectively. Removing logging slash was commonly used to combat problems with bark beetles, as indicated by 27% of respondents.

The majority of forest managers surveyed indicated that knapweeds (including all species in the *Centaurea* genus) and common tansy (*Tanacetum vulgare*) are the most commonly managed invasive plant species (Figure 11). Seventy-three percent of respondents indicated managing knapweeds and 53% of respondents managed tansy. A third of respondents (33%) indicated managing buckthorn species (*Rhamnus cathartica* and/or *Frangula alnus*). Chemical and mechanical techniques were the two most common methods reported for managing invasive plants.

4.6 OTHER ISSUES

Just over half of respondents in 2017 identified that their silvicultural practices have changed over the past 5 years (n = 11 for change, n =9 for no change)(Table 6). The main changes that organizations implemented include using different silvicultural systems (n = 3), increasing harvesting intensity (n=2), and shifting politics (n=2). Other responses to questions include underplanting, thinning for vigor, logistics due to personnel, increased salvage harvesting due to weather, and changes in the biomass market. These aspects are not surprising and have been identified with different questions in the previous section, i.e., increased concern regarding forest health threats like EAB triggering different silvicultural practices. It is interesting to note that two respondents identified some kind of politics influencing forest management.

In 2017, there was a 50/50 (n=20) split in organizations and their views on the ease of implementing site-level guidelines (Table 7). Because Guideline implementation rates were generally high among all ownership groups in 2008 (Rossman et al. 2018), we did not ask about implementation of specific Guidelines. We were more interested in if there were general implementation difficulties and what they were. Organizations could identify multiple difficulties. The two most commonly identified difficulties include leave tree retention (n=5) and biomass utilization (n=3). Respondents also noted that infrastructure, soil compaction, and RMZs contributed to difficulty in meeting site-level guidelines. As additional information, especially regarding leave tree retention importance for wildlife, continues to be gathered and distributed and as new foresters continue to enter the work force that have been taught about site level guidelines in school we expect difficulties to decrease in some areas (Grinde et al. 2017). There is less research in other areas including infrastructure and soil compaction, especially since average winter temperatures have warmed and are predicted to continue increasing. The 1996 survey notes that 58% of harvesting operation occurred in the winter. Surveys of logging business owners in 2011 and 2016 suggested that 51% and 56% of volume, respectively, was harvested during the winter season (Blinn et al. 2014, Blinn et al. 2019). Changing winter conditions and also assessing the trade-offs of harvesting on non-frozen ground may impact the ability of organizations to meet site level guidelines for soil compaction. Additional information

regarding these practices and the development of metrics will be needed to aid in forest management decisions.

4.7 TRENDS IN SILVICULTURAL PRACTICES

There continue to be distinct differences in silvicultural systems and forest management styles among forest ownership groups. The NMS ordination resulted in a two dimensional solution explaining 99.4% of the variation with a final instability of 0.0 and final stress of 2.49. Ordination is a useful tool since it allows multiple variables to be used and does not assume linear relationships among variables. The results from Figure 12 displays points in ordination space. Points that are closer together are more similar and responding to similar gradients; likewise points that are further away are more dissimilar and responding to different gradients. The gradients in this analysis are the different aspects of forest management: acreage, harvest level, and types of treatments applied.

For example, we see that county and state ownership are pretty close in ordination space and share some similarities in terms of types and intensity of treatments used but are more dissimilar to tribal ownerships. This difference represents a greater area of ownership and higher level of harvest intensity, as well as a greater use of seed tree silvicultural systems and commercial thinning. There has been the greatest shift among years in forest industry ownership which may represent the shift from private, vertically integrated companies to timberland investment management organizations (TIMOs) and real estate investment trusts (REITs). However, we do see movement towards the silvicultural systems used in the 1996 survey.

There continues to be strong separation based on the use of chemical herbicide for site preparation and TSI. There was greater use of mechanized methods by tribal ownerships and no chemical use by federal organizations; that represents a strong driver of Axis 2. Additionally, pre-commercial thinning is strongly correlated to Axis 2. The lack of herbicide usage continues influence and differentiate federal organizations from other organizations groups. The “No Herbicide Use” represents a hand-shake agreement among all National Forests in the Great Lakes Region and was started in 1990. There has been talk among a few National Forests in the Great Lakes including ones in the Minnesota in potentially using herbicide in the future (M Winmduller-Campione personal communication with FS silviculturists in the region); if there is a change in herbicide use federal ownership will likely be more similar to county and state organizations.

7. CONCLUSIONS

Silviculture and silvicultural practices are dynamic and will continue to evolve and shift within Minnesota. Different land owners and land managers, public and private, will continue to shift their silviculture as values, markets, and goals continue to evolve and shift. Other drivers including invasive plant, insect, and animal species; and changing disturbance patterns from year to year will further influence silviculture practices applied across the landscape. Forest management in Minnesota is composed of multiple organizations that provide different resource management styles and opportunities.

Several trends are evident in the results presented here. On the one hand, clearcutting remains the dominant system used across Minnesota's forests, occurring on about 72% of the harvest area. Nonetheless, all ownerships are using uneven-aged systems and the acreage treated in those systems are stable or higher than previous reports. Similarly, 2017 respondents indicated a lower average harvest intensity than in previous years, as well as a higher percentage of harvest acres in thinnings relative to other treatments in 2017 than in earlier reports. Together, these findings suggest an increased focus on silviculture to promote stand resilience, complexity, and heterogeneity, all widely viewed as important attributes to maintain forest health and resilience under changing climatic conditions.

Reduced acreage treated in site preparation and timber stand improvement may be due to reduced investment in intermediate treatments or may be due to the timing of a large scale blow down. Intermediate treatments have the potential influence future stocking, stand growth, and financial value. Quickly regenerating harvested stands and promoting rapid forest growth also increases the rate at which forests sequester atmospheric carbon.

Prescribed fire continues to be used very infrequently and may be an important tool for discussion in the future especially for fire-dependent forest communities. Herbivory protection is happening across all ownerships and in multiple different forms. Herbivory is likely impacting the regeneration of multiple species but especially eastern white pine and northern white cedar which were rated as being especially difficult to regenerate. Forest health concerns, both native and invasive species, are influencing forest management decisions with greater proactive management for EAB. Additionally, forest managers are increasingly promoting mixed species stands to build resilience to forest health threats by reducing monocultures. Finally, some organizations have already shifted practices within the last five years to account for current and predicted future changes. As climate change continues to influence natural resource managers, silviculturists will continue to use their toolbox to maintain the multiple benefits that forests provide.

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9. TABLES

Table 1. Summary of 2017, 2008, and 1996 silvicultural survey response for acreage and volume harvested. Data for 2008 and 1996 surveys are from D’Amato et al. (2009) and Puettmann and Ek (1999), respectively.

Variable	2017				2008				1996			
	n	Reported	Min	Max	n	Reported	Min	Max	n	Reported	Min	Max
Timberland (ac)	22	10,367,761	3,061	5,800,000	26	9,865,694	4,258	4,500,000	25	7,720,204	5,400	2,600,000
Total volume harvested (cords)	22	1,559,921	0	671,625	26	1,973,289	1,873	783,240	25	1,965,164	1,474	533,000
Fuelwood (cords)	20	17,620	0	3,120	26	10,080	50	3,400	25	63,468	50	20,000
Average clearcut size (ac)	22	17	0	120	26	29	10	135	25	24	6	50
Average partial cut (ac)	22	30	0	91	22	25	12	49	21	27	3	200
Total area in silvicultural systems (ac)	22	90,516	0	47,300	26	125,234	241	41,000	25	99,297	126	41,546
Cords harvested/acre timberland	21	0.15	-	-		0.20	-	-		0.25	-	-
Cords harvested/acre timber sale	22	20.8	-	-		15.8	-	-		19.8	-	-

Table 2. Reported silviculture survey results and statewide estimates for Minnesota, 2017, 2008, 1996, and 1991.

Variable	Survey results				Statewide estimate ¹			
	2017	2008	1996	1991	2017	2008	1996	1991
<i>Ownership, harvesting and regeneration</i>								
Timberland ownership (ac)	10,367,761	9,865,694	7,720,204	7,848,031	15,815,400	14,988,700	14,723,200	14,723,200
Total volume harvested (cords)	1,559,921	1,973,290	1,965,164	1,858,849	2,514,286	2,924,500	3,810,000	3,530,333
Harvesting operations (ac)	90,516	88,965	99,297	90,128	145,894	134,209	192,514	171,155
Regeneration (ac)	74,180	102,380	85,786	84,991	119,564	130,257	166,380	161,400
<i>Acres by silvicultural system and thinning (% of total acres in parentheses)</i>								
Clearcut ²	65,607 (72)	97,908 (78)	85,294 (86)	82,017 (91)	105,746 (72)	128,167 (78)	163,956 (86)	152,328 (91)
Strip clearcut	25 (0)	0 (0)	234 (0)	901 (1)	40 (0)	0 (0)	454 (0)	1,711 (1)
Seed tree	2,455 (3)	1,974 (2)	1,356 (1)	0 (0)	3,957 (3)	3,002 (2)	2,629 (1)	0 (0)
Shelterwood	1,887 (2)	2,830 (2)	789 (1)	0 (0)	3,041 (2)	4,303 (2)	1,530 (1)	0 (0)
Selection (group and single-tree)	5,276 (6)	4,712 (4)	1,022 (1)	1,802 (2)	8,504 (6)	7,164 (4)	1,981 (1)	3,422 (2)
Thinning (commercial)	15,266 (17)	17,809 (14)	10,602 (11)	5,408 (6)	24,606 (16)	27,044 (14)	20,555 (11)	1,0270 (6)

¹ Statewide estimates were derived by multiplying the respondent silvicultural system acreages by an expansion factor based on the reported statewide harvest level in 2016 divided by the sum of the respondent reported harvests. This approach expanded respondent acreages in silvicultural systems using an expansion factor based on the reported statewide harvest levels divided by the respondent reported harvests (2,514,286 cords/ 1,559,921 cords = 1.61). The statewide harvest level used was an estimate, as final mill survey numbers had not been received at the completion of our study. Preliminary estimates provided by Scott Hillard, MN Department of Natural Resources.

² Clearcut is defined as greater than 5 acres, with or without residuals. This estimate includes patch clearcuts for 2008, 1996, and 1991 surveys. Patch clearcuts were not included in 2017 survey.

Table 3. Reported harvesting activities by ownership within Minnesota in 2017. Data represent 66% of all timberland in Minnesota.

Variable	Ownership group						
	Survey Total	State	County	Federal	Forest Industry	Tribal	Non-profit
<i>Ownership, harvesting and regeneration</i>							
Timberland ownership (ac)	10,367,761	5,800,000	2,136,707	1,380,335	616,516	423,700	10,501
Total volume harvested (cords)	1,559,921	671,625	592,083	166,429	100,367	27,812	1,605
Harvesting operations (ac)	90,516	40,500	29,586	10,333	8,573	1,391	133
Regeneration (ac)	74,180	22,461	31,389	10,764	7,743	1,746	76
<i>Acres by silvicultural system and thinning (% of total acres in parentheses)</i>							
Clearcut	65,607 (72)	29,692 (73)	23,773 (80)	4,292 (42)	6,702 (78)	1,055 (76)	93 (70)
Strip clearcut	25 (0)	0 (0)	25 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Seed tree	2,455 (3)	1,572 (4)	269 (1)	614 (6)	0 (0)	0 (0)	0 (0)
Shelterwood	1,887 (2)	432 (1)	447 (1)	891 (9)	37 (0)	80 (6)	0 (0)
Single-tree selection	2,140 (2)	144 (0)	287 (1)	1,037 (10)	672 (8)	0 (0)	0 (0)
Group selection	3,136 (4)	1,520 (4)	1,096 (4)	339 (3)	108 (2)	70 (5)	3 (2)
Thinning (commercial)	15,266 (17)	7,140 (18)	3,690 (12)	3,159 (30)	1,054 (12)	186 (13)	37 (28)

Table 4. Reported acres of silvicultural practices by ownership in Minnesota in 2008. Data represent 66% of all timberland in Minnesota.

Variable	Ownership group							
	n	Survey Total	State	County	Federal	Forest Industry	Tribal	Non-profit
<i>Regeneration</i>								
Underplanting	18	4,461	450	167	3,929	35	80	0
Direct seeding	18	3,759	2,592	793	315	59	0	0
Cutting	16	0	0	0	0	0	0	0
Two-planting	16	897	552	75	10	110	150	0
Natural regeneration, from sprouts	19	48,907	14,482	24,941	4,191	4,065	1,310	18
Natural regeneration, from seed	19	10,776	4,385	3,548	370	2,109	316	58
Average percent conifer	16	36	13	34	25	42	30	58
Average percent hardwood	16	64	87	66	75	58	70	42
TOTAL		74,180	22,461	31,389	10,764	7,743	1,746	76
<i>Site preparation</i>								
Chemical-aerial	17	17	17	0	0	0	0	0
Chemical-ground	17	2,295	445	1,780	0	70	30	0
Prescribed burning	17	351	100	0	81	10	160	0
Mechanical	17	6,026	1,449	2,308	1,247	640	330	52
TOTAL		8,689	2,011	4,088	1,328	720	520	52
<i>Timber stand improvement</i>								
Chemical release-aerial	18	487	487	0	0	0	0	0
Chemical release-ground	19	2,604	648	1,691	0	60	200	5
Mechanical/manual release	19	5,151	0	1,619	1,880	1,507	145	0
Precommercial treatments	20	1,023	744	0	0	155	120	4
Residual stem felling	17	260	0	10	0	0	250	0
TOTAL		9,525	1,879	3,320	1,880	1,722	715	9
<i>Salvage harvesting</i>								
Salvage harvesting	20	5,852	3,656	2,155	0	155	30	0
<i>Protection from herbivory</i>								
Bud capping	20	20,296	7,632	6,511	5,355	400	300	98
Cages around individual trees	16	541	0	10	495	0	0	36
Fences around areas (exclosures)	14	9	0	0	0	0	0	9
Sprays or repellents	14	253	203	50	0	0	0	0
Other: hand release	1	6,164	0	0	6,164	0	0	0
Other: Exclosure of small groups	1	2	0	0	0	0	0	2
TOTAL		27,265	7,835	6,571	12,014	400	300	145

Table 5. Summary of biofuels harvests reported within Minnesota in 2017 and 2008.

Variable	Ownership group and survey year													
	Survey Total		State		County		Federal		Forest Industry		Tribal		Non-profit	
	2017	2008	2017	2008	2017	2008	2017	2008	2017	2008	2017	2008	2017	2008
Number of respondents	20	15	1	1	10	7	1	2	3	1	3	4	2	-
Number of respondents that harvested biofuels	11	-	1		4		1		3		1		1	-
Total ac of biofuels harvest	7,592	7,642	2,400	5,467	3,071	1,675	736	0	1,307	300	20	200	58	-
Average percent of biofuels removed on second entry	3.3	21	-	25	10	36	0	-	0	-	0	0	0	-
Average percent of biofuels harvested where roundwood was sold as biofuel	26	20	-	25	23	36	0	-	63	10	0	10	5	-
Average percent of biofuels on second entry involved backhauling slash	0	-	-	-	0	-	-	-	0	-	0	-	0	-
Location of slash before collection (average percent):														
Windrows	0	0	-	0	0	0	0	-	0	0	0	0	0	-
Piles at landing	23	75	-	50	33	60	50	-	0	100	0	90	100	-
Scattered	25	3	-	0	50	0	50	0	50	0	0	10	0	-
Other locations	37	-	-	-	0	-	0	-	100	-	100	-		-
Average percent of biofuel harvests for which:														
Sub-merchantable materials were harvested	36	72	-	75	47	65	60	-	45	75	40	-	95	-
Hard snags were harvested	6	17	-	15	5	2	0	-	0	50	60	0	0	-

Table 6. Number of responses to the question “Have your silvicultural practices changed over the last five years?”

Ownership	Yes	No
State	0	1
County	5	4
Federal	2	0
Forest industry	1	2
Tribal	2	1
Non-profit	1	1
All ownerships	11	9

Table 7. Number of responses to the question “Which site-level guideline(s) have been the most difficult for your staff to meet?”

Ownership	No difficulties	At least one difficulty
State	0	1
County	4	6
Federal	0	1
Forest industry	2	1
Tribal	2	1
Non-profit	2	0
All ownerships	10	10

Table 8. Number of responses to the question “How do you expect your silvicultural practices to change in the next five years?”

Ownership	Number of responses
Managing for emerald ash borer	7
Reliance on natural regeneration	2
Precommercial thinning	2
No change	2
Regeneration in lowland conifers	2
Age class management	2
Maintaining structure when rotations decrease	1
Biomass market loss	1
Salvage with weather	1
Increased herbicide use	1
Forest inventory	1
Forest health issues	1
Working across agencies	1

10. FIGURES

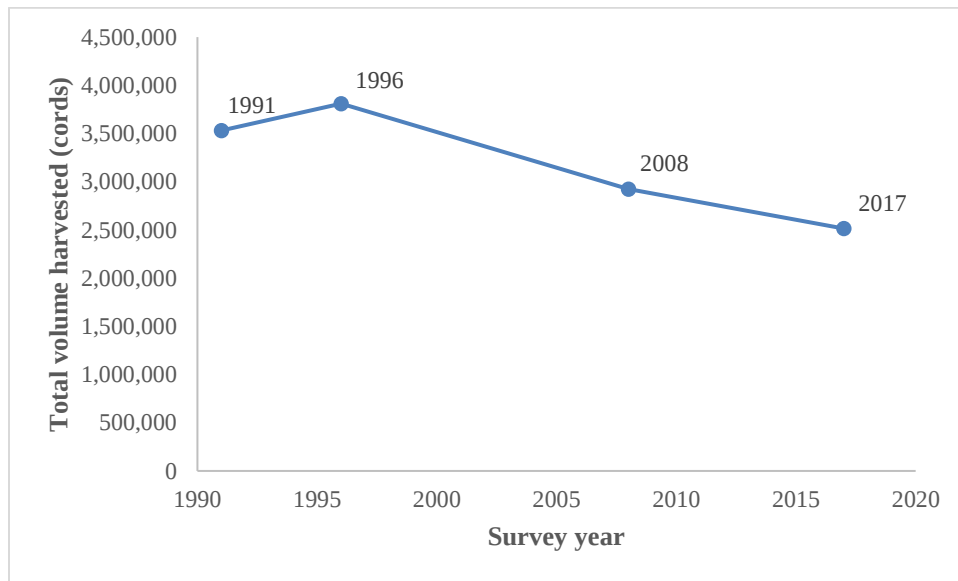


Figure 1. Statewide estimates of total annual timber volume harvested for four survey years in Minnesota.

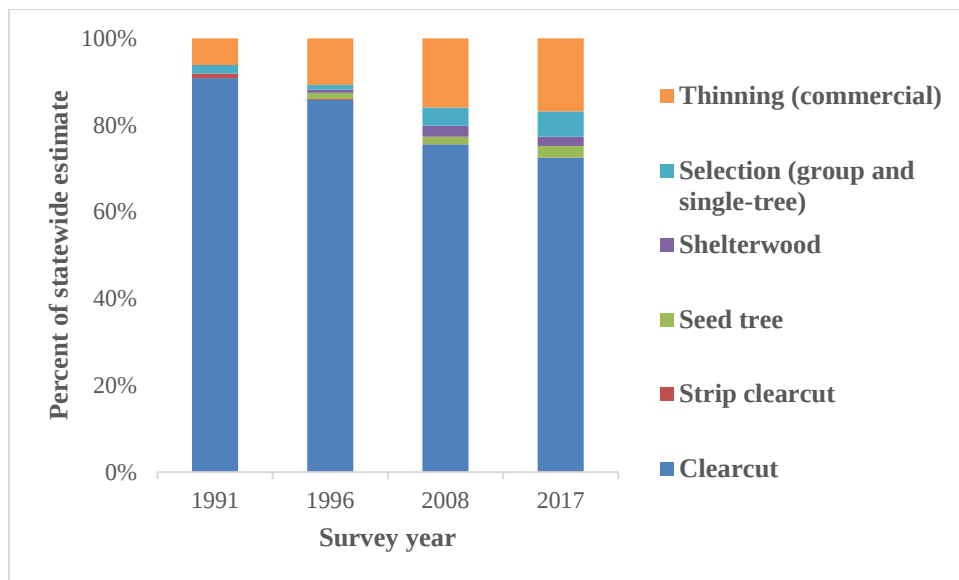


Figure 2. Trends in statewide estimates of silvicultural practices and thinning for four survey years in Minnesota.

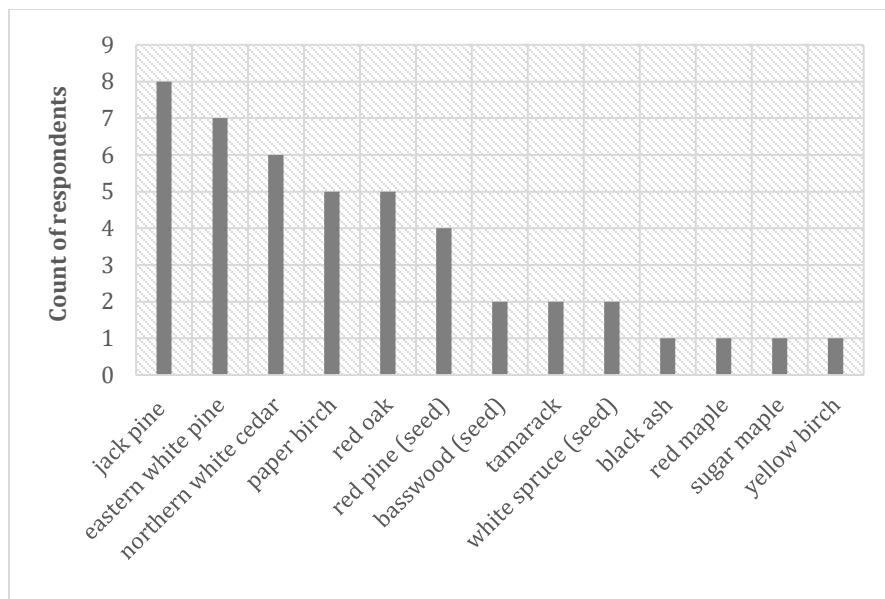


Figure 3. Number of responses to the question “Which species are you currently having the most difficulty regenerating?”

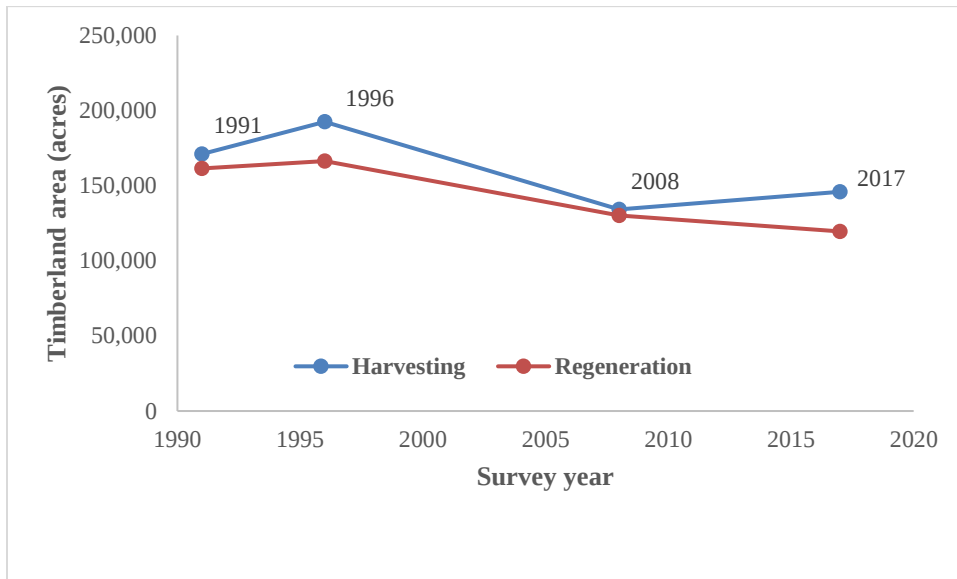


Figure 4. Statewide estimates of area in harvesting and regeneration for four survey years in Minnesota.

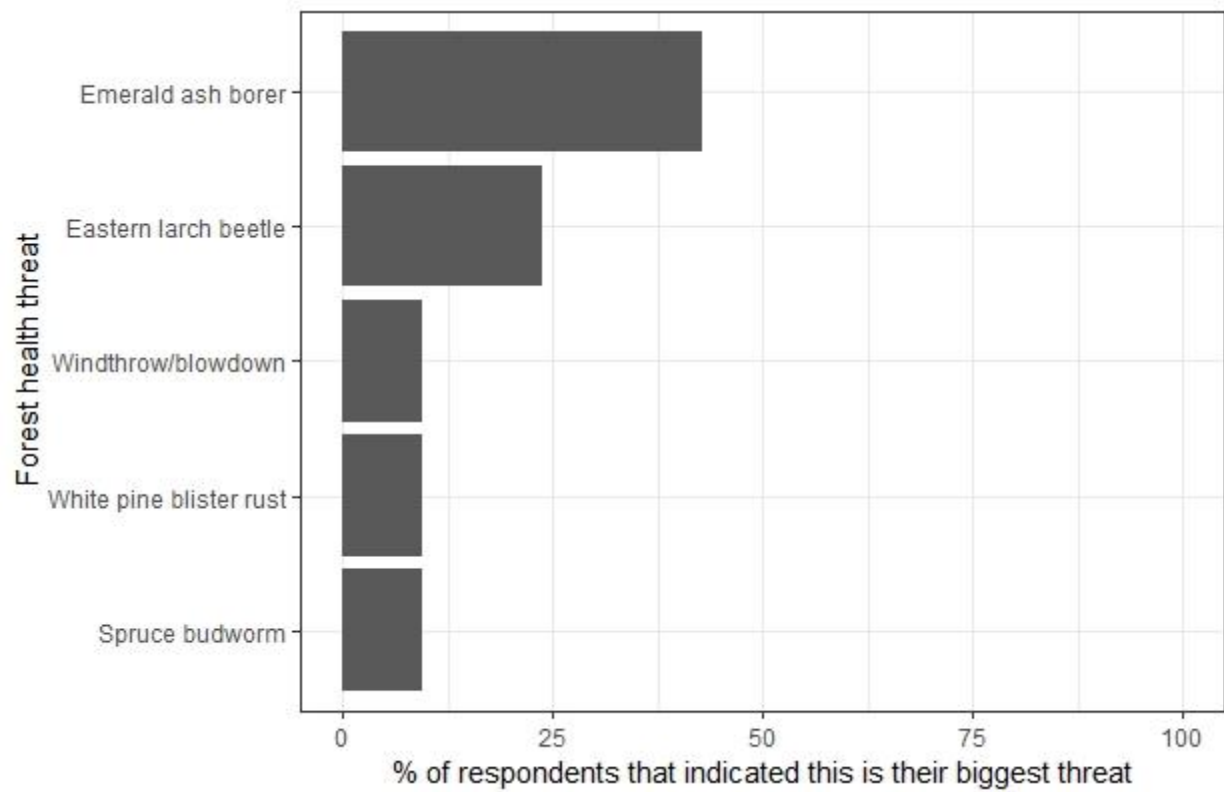


Figure 5. Percent of respondents ($n = 21$) that indicated an issue was their biggest forest health threat in Minnesota in 2017.

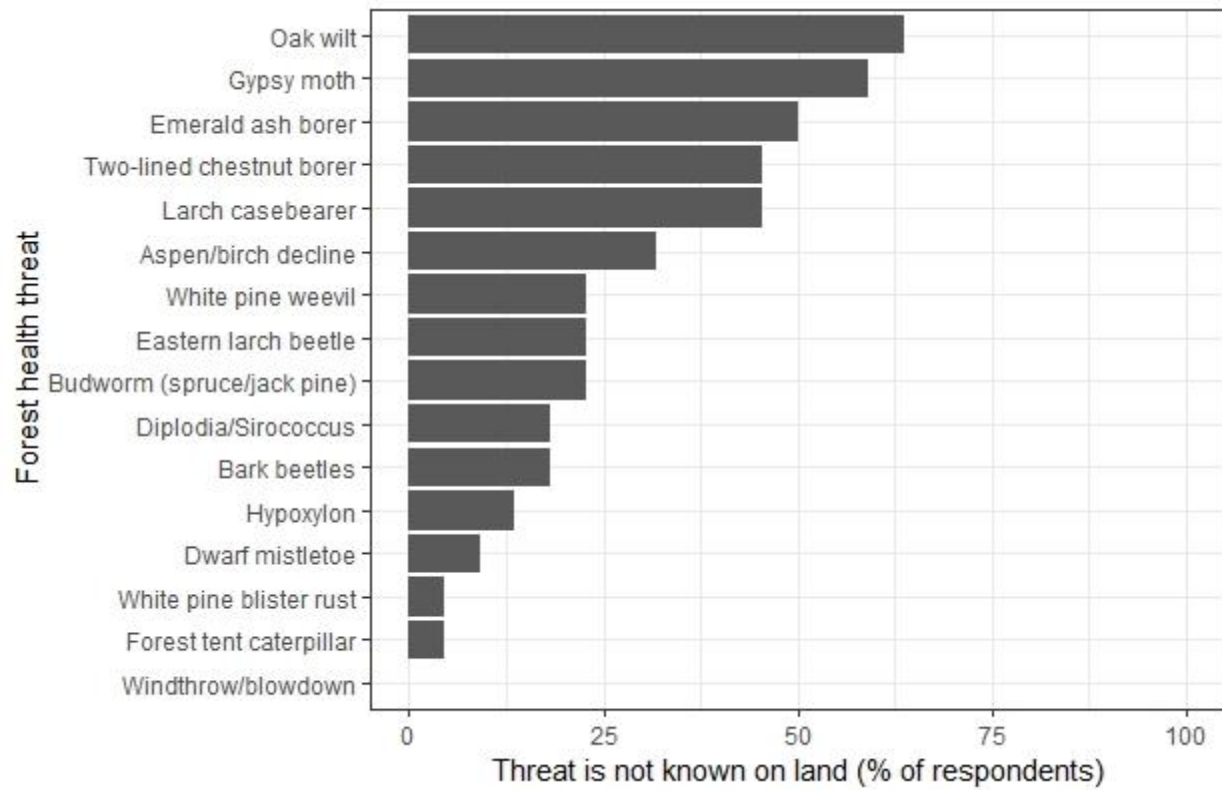


Figure 6. Percent of respondents that indicated forest health threat is not known on their land within Minnesota in 2017.

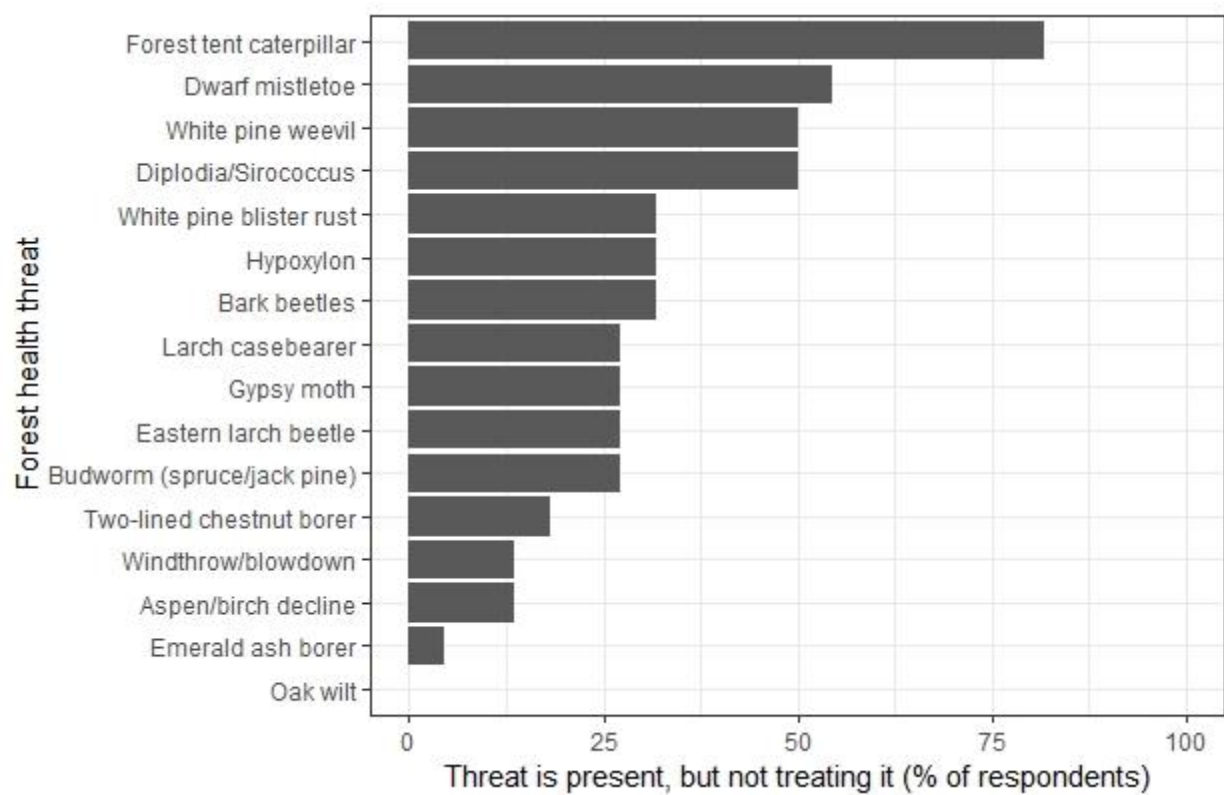


Figure 7. Percent of respondents that indicated forest health threat is present on their land within Minnesota in 2017, but did not treat it.

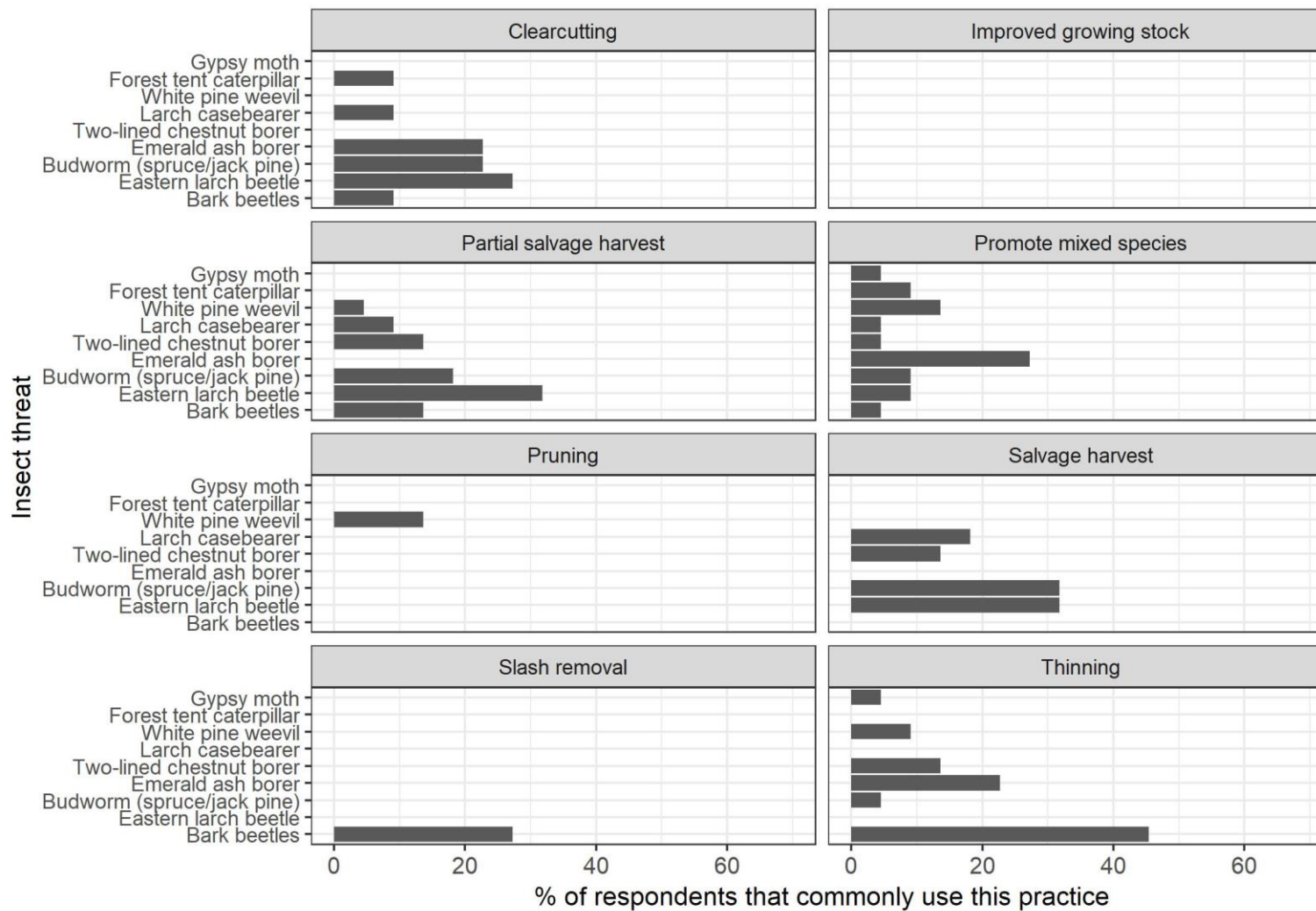


Figure 8. Percent of respondents that commonly used a silvicultural practice to manage an insect forest health threat within Minnesota in 2017.

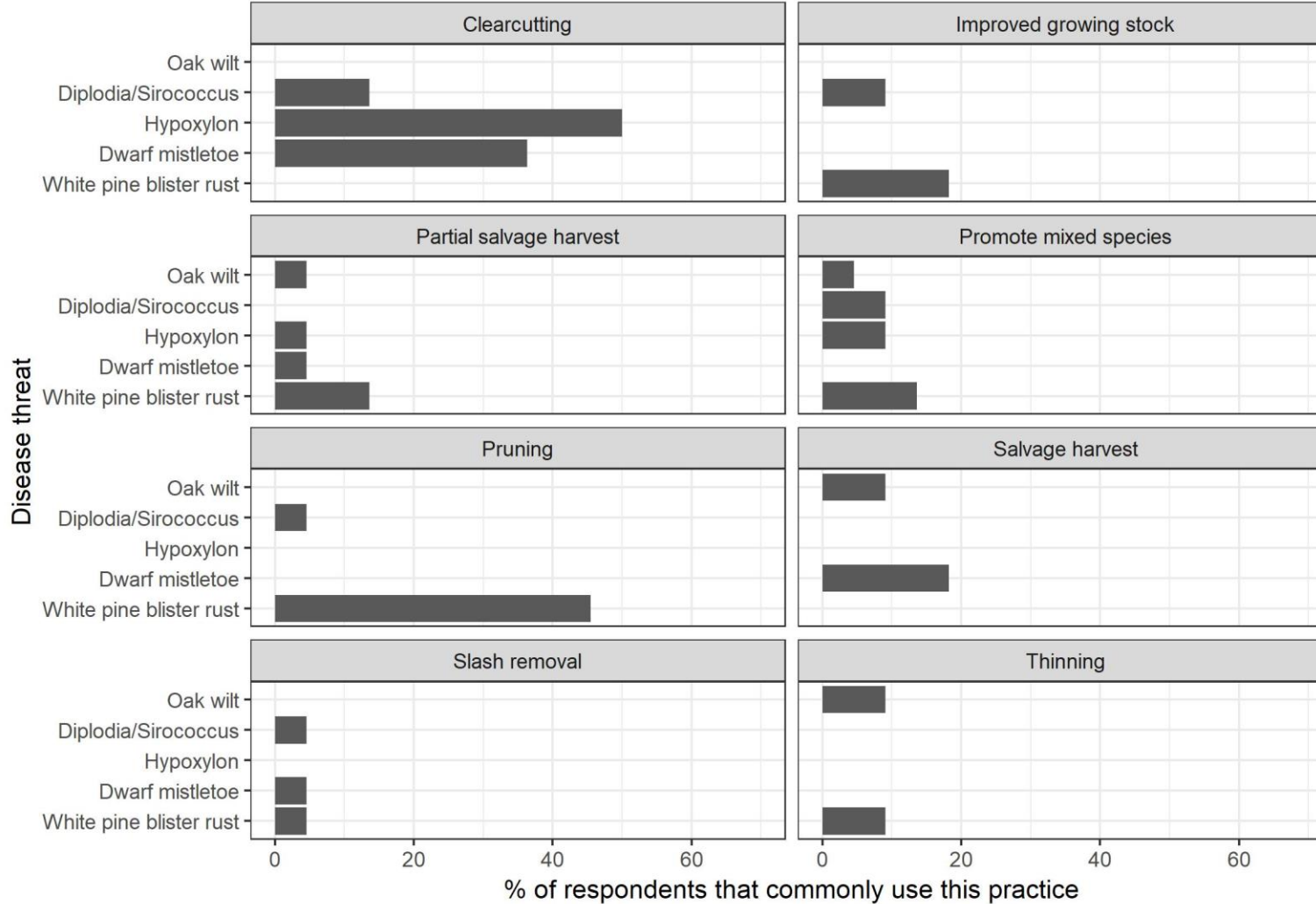


Figure 9. Percent of respondents that commonly used a silvicultural practice to manage a disease forest health threat within Minnesota in 2017.

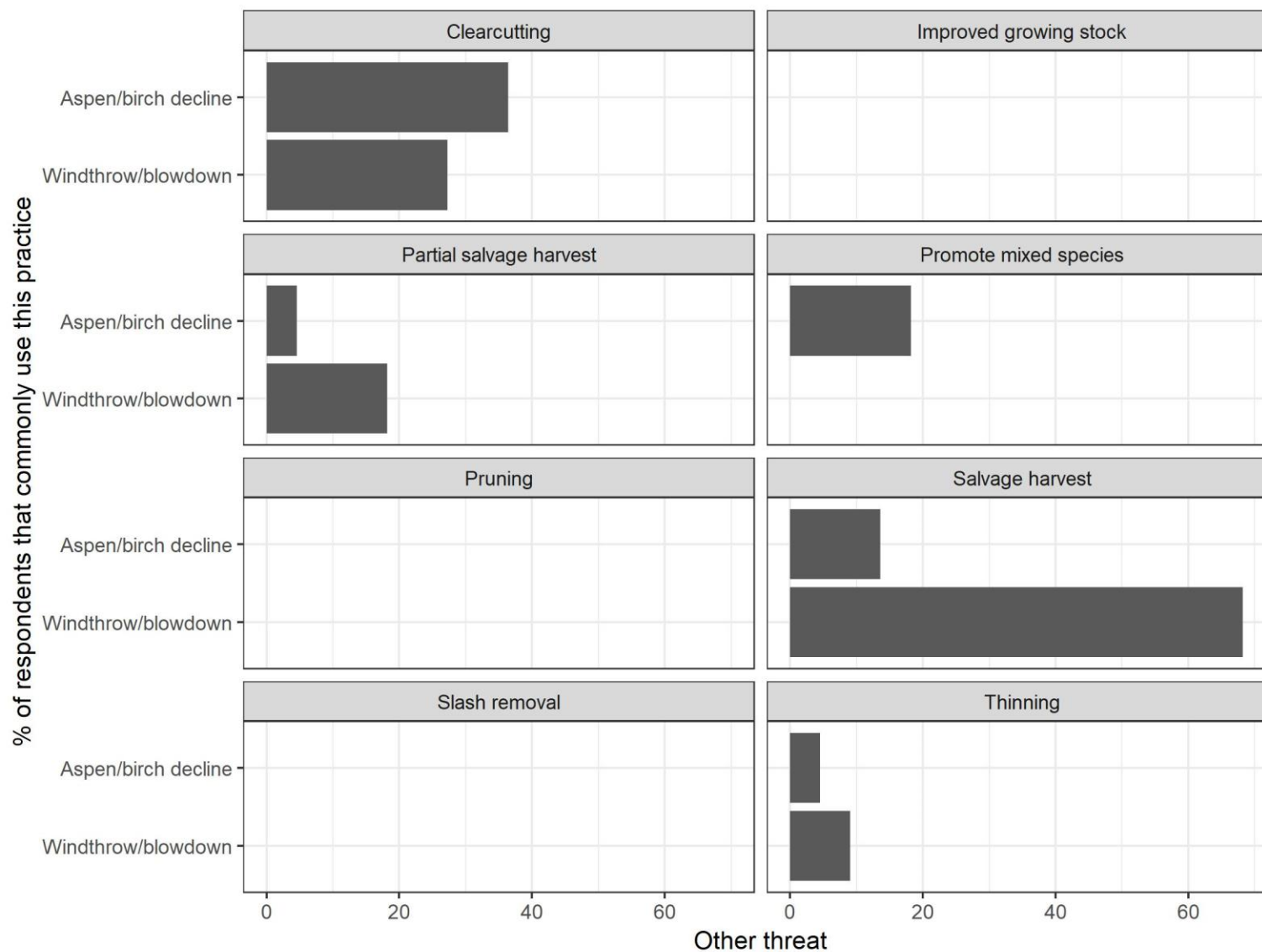


Figure 10. Percent of respondents that commonly used a silvicultural practice to manage other forest health threats within Minnesota in 2017.

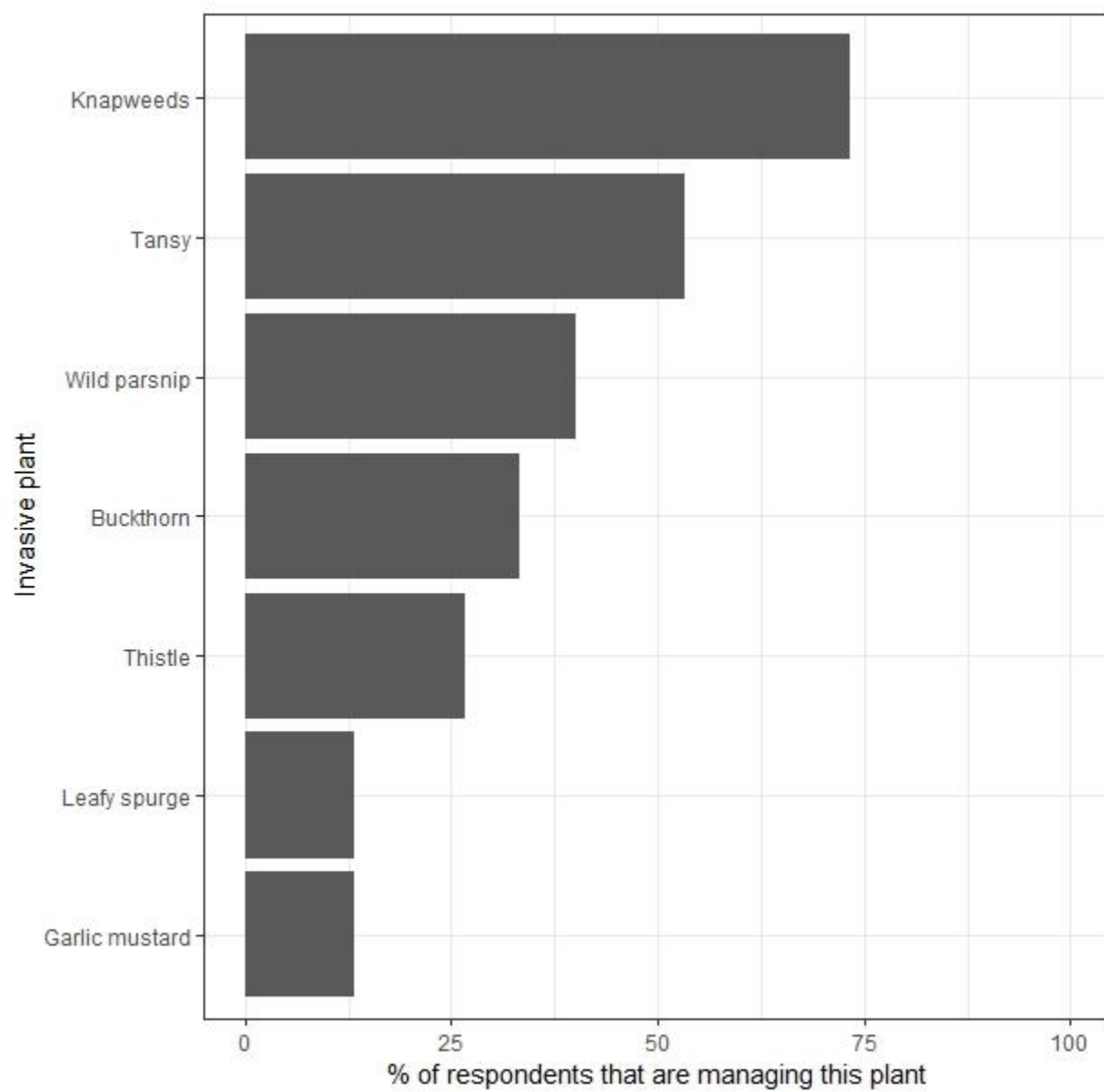


Figure 11. Percent of respondents that are managing a specific invasive plant within Minnesota in 2017.

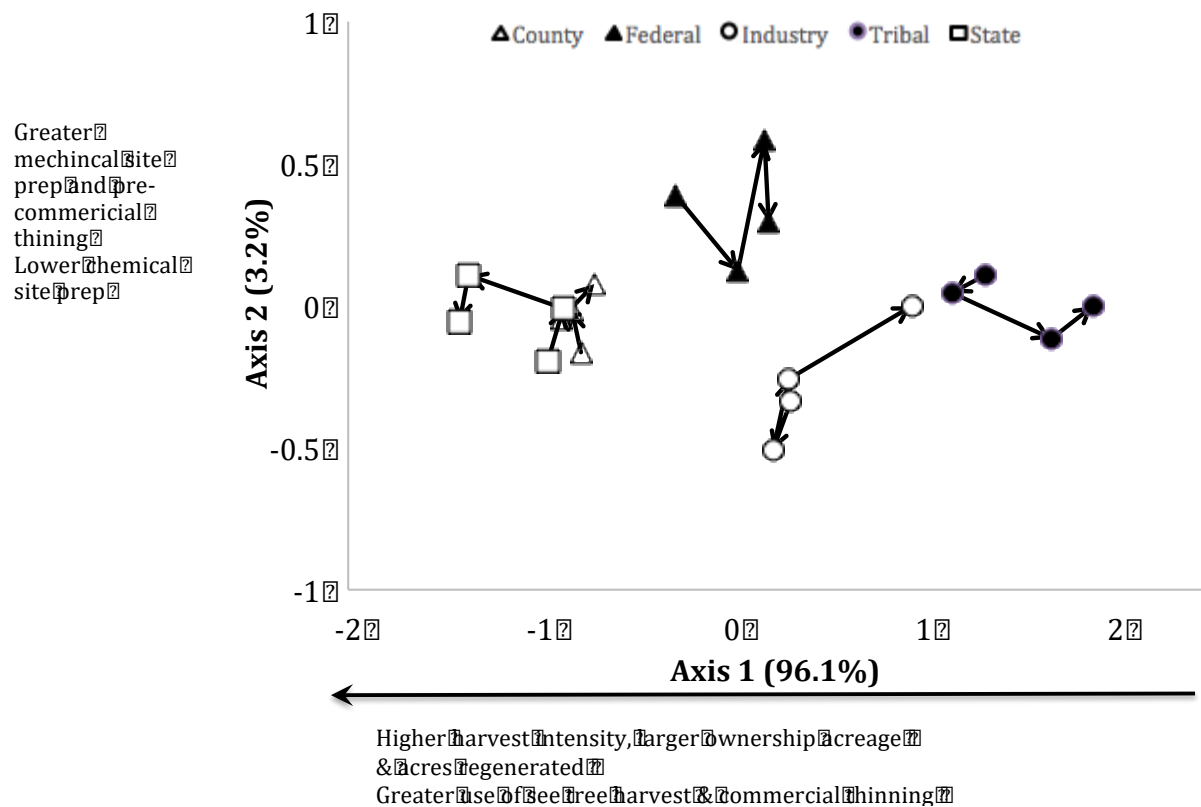


Figure 12. Non-metric multidimensional scaling (NMS) NMS ordination explained 99.4% of the variation with a final instability of 0.0 and final stress of 2.49. Two axes are displayed: Axis 1 along the X and Axis 2 along the Y. The percentage of variation explained is in parenthesis next to the axis labels. Below each axis is an arrow which represents the relationship among variables. For example, more negative scores on Axis 1 are correlated to higher harvest intensity, larger ownership, and greater use of seed tree harvest and commercial thinnings. More positive numbers along Axis 2 are related to greater mechanical site preparation, pre-commercial thinning, and lower use of chemical site preparation.

11. APPENDICES

APPENDIX A: Questionnaire: Silvicultural Practices in Minnesota

Questionnaire: Silvicultural Practices in Minnesota



Contact:

Marcella Windmuller-Campione
Department of Forest Resources
University of Minnesota
(612) 624-3699
mwind@umn.edu



The purpose of this questionnaire is to learn more about the silvicultural and forest health practices applied across Minnesota in 2016 or your most recently completed fiscal year.

The questions should take a couple of hours to complete. Your organization's participation is entirely voluntary and there is no penalty for choosing not to complete the questionnaire. Your answers will never be associated with you personally and only aggregate results, with no personal identifiers, will be reported. (The name you provide will only be used to halt reminders once you have returned your questionnaire.)

You may complete and submit the questionnaire in either of the following ways:

- 1) Fill in the digital (PDF) questionnaire, then **save the file with a new name** and email the completed version to sfec@umn.edu; or
- 2) Print, handwrite your responses, and mail a hard copy
to Marcella Windmuller-Campione
RE: Silviculture Study
Cloquet Forestry Center
175 University Road
Cloquet, MN 55720

If you wish to comment on any question or expand on your response, feel free to use the space allotted at the end of this survey.

See the enclosed sheet for definitions of the terms used throughout the questionnaire. Terms marked with an asterisk* appear in the glossary.

Respondent's Name: _____

Organization: _____

If possible, please complete the survey for the period January 1 to December 31, 2016. If your database structure makes this a challenge, you may report on a different 12-month period (e.g. your most recently completed fiscal year).

The 12-month period that you are reporting on runs from:

_____ (month, year) through the end of _____ (month, year).

PART 1: ANNUAL FOREST MANAGEMENT OPERATIONS

Throughout the questionnaire, answers should be based on timberland only (all forested land available for management). **If you don't have exact figures available, provide your best estimates throughout the questionnaire.**

1.1 Which of the following best describes the ownership of the land base you are reporting on? (Check one option.)

Federal

State

County

Private (including corporate or TIMO/REIT)

Private (forest industry)

Tribal

Other (please specify): _____

1.2 What was your organization's total timberland acreage during the reporting period?

_____ acres

1.3 How many acres were harvested during the reporting period?

_____ acres

1.4 What was the total volume harvested? Please report cords plus additional MBF or tons, where appropriate. (MBF = thousand board feet):

1.4.1 Total (excluding firewood):

_____ cords of pulpwood

_____ MBF of sawtimber

_____ tons biofuels/biomass

1.4.2 Firewood

_____ cords

_____ tons

PART 2: SILVICULTURAL ACTIVITIES

Please base your response to the following questions on tracts that were offered for sale during the reporting year, regardless of whether the tract sold or not. Acreage should include the entire sale area, including reserve patches. If none, please write in 0.

2.1 How many different sales were offered?

_____ sales

2.2 What was the total acreage of all sales offered?

_____ acres

2.3 How many sales were offered, but not sold?

_____ sales

2.4 Some timber sales involve multiple blocks, sometimes with different harvest treatments. For the following questions, estimate the **average size and number of harvest blocks offered during the reporting year** for each silvicultural system. If none, please write in 0.

2.4.1 Clearcut* (including coppice) with or without residuals:

_____ acres in _____ harvest blocks

2.4.2 Strip clearcut*:

_____ acres in _____ harvest blocks

2.4.3 Shelterwood*:

_____ acres in _____ harvest blocks

2.4.4 Seed tree*:

_____ acres in _____ harvest blocks

2.4.5 Group selection*:

_____ acres in _____ harvest blocks

2.4.6 Single tree selection:

_____ acres in _____ harvest blocks

2.4.7 Thinning (commercial only):

_____ acres in _____ harvest blocks

2.5 From those acres **commercially** thinned (your response to 2.4.7 above), indicate the percentage of acres that used the following thinning methods (NOTE: Totals should add to 100%). If none, please write in 0.

2.5.1 Thinned from above _____ %

2.5.2 Thinned from below _____ %

2.5.3 Row thinning _____ %

2.5.4 Free thinning _____ %

2.6. From those acres **commercially** thinned (your response to 2.4.7 above), indicate the percentage of acres that were logger select*: _____ %

2.7 Estimate the total acreage receiving each of the following **timber stand improvement** or release methods. If none, please write in 0:

2.7.1 Chemical release – aerial: _____ acres

2.7.2 Chemical release – ground: _____ acres

2.7.3 Mechanical release: _____ acres

2.7.4 Noncommercial thinning: _____ acres

2.7.5 Residual stem felling: _____ acres

2.8 Estimate the acreage receiving a salvage harvest*. If none, please write in 0.

Salvage harvest: _____ acres

2.9 If there are other silvicultural treatments not listed above, specify them here and estimate the number of acres on which each occurred. NOTE: Omit biofuels* harvests here, which will be addressed in the next section. If left blank, we will assume no other treatments were applied.

Other treatment 1: _____ on _____ acres

Other treatment 2: _____ on _____ acres

Other treatment 3: _____ on _____ acres

2.10 Do you use a silvicultural prescription form?

_____ Yes _____ No

If yes, please email or mail a blank copy of your silvicultural prescription form to the contact provided at the end of the survey.

PART 3: BIOFUELS* HARVESTS

3.1 How many acres received any harvest for biofuels* during the reporting period?

Biofuel harvest: _____ acres

3.2 For what percentage of biofuels harvest sites were biofuels removed through a second entry into the stand after the primary harvest was complete?

Second entry: _____% of biofuels harvest sites

3.3 For what percentage of biofuel harvest sites was roundwood sold as biofuel?

Roundwood sold as biofuel: _____% of biofuels harvest sites

3.4 For biofuel harvests involving a second entry, what percentage of biofuel harvest sites involved first backhauling of slash?

Backhauling slash: _____% of biofuels harvest sites

3.5 For biofuel harvests, where was the biofuel material located prior to collection?

3.5.1 Windrows: _____% of biofuels harvest sites

3.5.2 Piles at a landing: _____% of biofuels harvest sites

3.5.3 Scattered: _____% of biofuels harvest sites

3.5.4 Any other location: _____% of biofuels harvest sites

3.6 For what percent of biofuel harvest sites were submerchantable materials or snags harvested?

3.6.1 Sub-merchantable materials harvested: _____% of biofuels harvest sites

3.6.2 Hard snags harvested: _____% of biofuels harvest sites

PART 4: REGENERATION METHODS

4.1 Estimate the areas regenerated during the reporting year. If none, please write in 0:

4.1.1 Total regeneration including each of the following methods:

_____ acres including _____% conifer and _____% hardwood species

4.1.2 Underplanting:

_____ acres including _____% conifer and _____% hardwood species

4.1.3 Seeding:

_____ acres including _____% conifer and _____% hardwood species

4.1.4 Cuttings (e.g., hybrid poplar):

_____ acres including _____% conifer and _____% hardwood species

4.1.5 Two or more years of successive planting:

_____ acres including _____% conifer and _____% hardwood species

4.1.6 Natural regeneration from sprouts or suckers:

_____ acres including _____% conifer and _____% hardwood species

4.1.7 Natural regeneration from seed:

_____ acres including _____% conifer and _____% hardwood species

4.2 Other regeneration methods used (please specify). If left blank, we will assume no other regeneration methods were used.

Other method 1: _____ on _____ acres

Other method 2: _____ on _____ acres

Other method 3: _____ on _____ acres

4.3 Estimate the area receiving protection from ungulate herbivory using each of the following methods. If none, please write in 0:

4.3.1 Total acreage protected from ungulate herbivory using any method:

_____acres

4.3.2 Bud capping:

_____acres

4.3.3 Cages around individual trees:

_____acres

4.3.4 Fences around larger areas (e.g., exclosures):

_____acres

4.3.5 Sprays or repellents:

_____Acres

4.3.6 Other herbivory protection methods used (please specify). If left blank, we will assume no other methods were used.

Other method 1: _____ on _____ acres

Other method 2: _____ on _____ acres

Other method 3: _____ on _____ acres

PART 5: SITE PREPARATION METHODS

5.1 Estimate the acreage receiving each of the following types of site preparation during the reporting year. If none, please write in 0:

5.1.1 Chemical-aerial:

_____ acres

5.1.2 Chemical-ground:

_____ acres

5.1.3 Prescribed burning:

_____ acres

5.1.4 Mechanical (scarification, root raking, etc.):

_____ acres

5.2 Other site preparation methods used (please specify). If left blank, we will assume no other methods were used.

Other method 1: _____ on _____ acres

Other method 2: _____ on _____ acres

Other method 3: _____ on _____ acres

PART 6: FOREST HEALTH

6.1 Next, we are interested in how you are addressing specific forest health threats. For each row of the following tables, please indicate **EITHER** that you are not managing that threat (and why) **OR**, if you are managing it, **indicate up to two** treatments/practices that you use most commonly to treat that threat on your land base.

6.1.1. Insect threats:

Are you managing this threat?	No. Why not?		or	Yes. Which practices do you use most commonly? (<i>select up to two most common</i>)							
	Threat is not known on our land	Present, but not treating it		Pre-emptive thinning for vigor	Clear-cutting (pro-actively)	Salvage harvest to liquidate after mortality	Partial salvage harvest (sanitation of infested material)	Promotion of mixed species	Slash removal	Improved growing stock	Pruning
Bark beetles											
Budworm (spruce/ jack pine)											
Eastern larch beetle											
Emerald ash borer											
Forest tent caterpillar											
Gypsy moth											
Larch casebearer											
Two-lined chestnut borer											
White pine weevil											
Other:											

6.1.2 Disease threats:

Are you managing this threat?	No. Why not?		or Yes. Which practices do you use most commonly? (<i>select up to two most common</i>)							
	Threat is not known on our land	Present, but not treating it	Pre-emptive thinning for vigor	Clear-cutting (pro-actively)	Salvage harvest to liquidate after mortality	Partial salvage harvest (sanitation of infested material)	Promotion of mixed species	Slash removal	Improved growing stock	Pruning
White pine blister rust										
Diplodia/Sirococcus										
Dwarf mistletoe										
Hypoxylon										
Oak wilt										
Other:										
Other:										

6.1.3 Other forest health concerns:

Are you managing this threat?	No. Why not?		or Yes. Which practices do you use most commonly? (<i>select up to two most common</i>)							
	Threat is not known on our land	Present, but not treating it	Pre-emptive thinning for vigor	Clear-cutting (pro-actively)	Salvage harvest to liquidate after mortality	Partial salvage harvest (sanitation of infested material)	Promotion of mixed species	Slash removal	Improved growing stock	Pruning
Windthrow/blowdown										
Ungulate herbivory										
Aspen and birch decline										
Other:										
Other:										
Other:										

6.1.4 If you are managing for forest health threats listed in the above tables, but are **using methods that are not listed**, indicate the threat and the methods used below. Be sure to check or write in **only up to two methods** per threat.

Forest health threat:_____ treatment method:_____

Forest health threat:_____ treatment method:_____

Forest health threat:_____ treatment method:_____

6.2 Which of the forest health issues listed in the tables in section 6 is your biggest threat?

6.3 Are you actively managing invasive plants?

_____ Yes _____ No

If YES, which invasive plants are you managing and by which techniques? List up to four plants.

Plant: _____ Technique: _____

Plant: _____ Technique: _____

Plant: _____ Technique: _____

Plant: _____ Technique: _____

PART 7: TRENDS IN SILVICULTURAL PRACTICES

7.1 How have your silvicultural practices changed over the past five years? What factors caused these changes?

7.2 Over the past five years, which site-level guideline(s) have been the most difficult for your staff to implement? Why?

7.3 Which species are you currently having the most difficulty regenerating?

74 How do you expect your silvicultural practices to change in the next five years?

75 Looking ahead to the next five years, what is your biggest silviculture and/or forest health concern?

PART 8: OTHER COMMENTS

8.1 Is there anything else you would like us to know about your silvicultural practices, plans or concerns about the future, or other issues? Please write your comments here.

Thank you! If completing the questionnaire digitally, **be sure to save the file with a new name** before closing so that your data are properly recorded. Then, either email the completed version to sfec@umn.edu; or, if submitting a hard copy, mail it to

Marcella Windmuller-Campione

RE: Silviculture Study
Cloquet Forestry Center
175 University Road
Cloquet, MN 55720

Please submit your silviculture prescription form in the same way.

If you have any questions about this survey, please contact Marcella Windmuller-Campione at (612) 624-3699 or sfec@umn.edu

THIS CONCLUDES THE QUESTIONNAIRE

APPENDIX B: Letters requesting participation in study

Initial contact letter

Subject: Survey of Silvicultural Practices in Minnesota

November 7, 2017

Sent on behalf of Marcella Windmuller-Campione:

Dear <Recipient>,

I'm writing to ask for your help with an important University of Minnesota study.

In the next few days you'll receive an emailed request to participate in this project by answering questions about your organization's silvicultural treatments over the past year. The purpose of the study is to better understand the silvicultural practices implemented across Minnesota timberland in the past year. These results will extend our understanding of trends dating back to 1991, providing important insight and information to policy makers, industry groups, and others. This effort is being funded by the Interagency Information Cooperative.

In order for the results to truly reflect the status of forest management in the state, it is important that each major forest landowner complete this questionnaire. Fortunately response rates have been quite high in the past, and we are counting on your help again this year.

We would like to do everything we can to make it easy and enjoyable for you to participate in the study. I'm writing in advance because many people like to know ahead of time that they will be asked to fill out a questionnaire. This research can only be successful with the generous help of people like you, on behalf of <Recipient Organization>.

I hope you will take some of your time to help us. Most of all, I hope that you enjoy the questionnaire and the opportunity contribute to our understanding of silviculture trends across Minnesota.

Sincerely,
Marcella Windmuller-Campione

Second contact letter

Subject: Survey of Silvicultural Practices in MN

November 9, 2017

Sent on behalf of Marcella Windmuller-Campione:

Dear <Recipient>,

I'm writing to ask for your help understanding the status of silvicultural treatments across Minnesota timberland. The best way we have to gain this understanding is to ask all different kinds of land owners to share their practices over the past year. As a representative of a major landowner and land management agency or company, your responses are important.

The questions should take a few hours to complete. Your organization's participation is entirely voluntary and there is no penalty for choosing not to complete the questionnaire. Your answers will never be associated with you personally and only aggregate results, with no personal identifiers, will be reported. (The name on the survey will only be used to halt reminders once you have returned your questionnaire.)

The questionnaire is designed to cover practices applied by a variety of landowners in Minnesota. If your database does not contain the requested information, please enter your best estimate.

Please submit your completed questionnaire as soon as possible but no later than December 31.

If you have questions or concerns about this study, I can be reached at mwind@umn.edu or (612) 624-3699. If you would like to talk to someone other than me, contact the University of Minnesota Research Participants' Advocate Line at (612) 625-1650 or submit feedback at <http://z.umn.edu/hrppfeedback>.

By taking some time to share information about your organization's silvicultural practices, you will be helping us, and the entire Minnesota forestry community, a great deal. I hope you enjoy completing the questionnaire. We look forward to receiving your responses as soon as possible.

Many thanks,
Marcella Windmuller-Campione

APPENDIX C: Glossary of Terms Used In Questionnaire: Silvicultural Practices in Minnesota

Silvicultural systems:

Clearcutting

A method of regenerating an even-aged stand in which a new age class develops in a fully exposed microclimate after removal, in a single cutting, of all trees in the previous stand. Regeneration is from natural seeding, direct seeding, planted seedlings, and/or advance reproduction. Cutting may be done in groups or patches (Group or Patch Clearcutting, not used in this questionnaire), or in strips (**Strip Clearcutting**). Clearcut stands may include reserve or residual trees.

Seed Tree

An even-aged regeneration method in which a new age class develops from seeds that germinate in fully exposed microenvironments after removal of all the previous stand except a small number of trees left to provide seed. Seed trees are removed after regeneration is established.

Shelterwood

A method of regenerating an even-aged stand in which a new age class develops beneath the moderated microenvironment provided by the residual trees. The sequence of treatments can include three distinct types of cuttings: (1) an optional preparatory cut to enhance conditions for seed production; (2) an establishment cut to prepare the seed bed and to create a new age class; and (3) a removal cut to release established regeneration from competition with the overwood. Cutting may be done uniformly throughout the stand (Uniform Shelterwood), in groups or patches (Group Shelterwood), or in strips (Strip Shelterwood).

Group Selection

A method of regenerating uneven-aged stands in which trees are removed, and new age classes are established, in small groups. The maximum width of groups is approximately twice the height of the mature trees, with small openings providing microenvironment suitable for tolerant regeneration and the larger openings providing conditions suitable for more intolerant regeneration. In the Group Selection System, the management unit or stand in which regeneration, growth, and yield are regulated consists of a landscape containing an aggregation of groups. (see Clearcutting)

Single Tree Selection

A method of creating new age classes in uneven-aged stands in which individual trees of all size classes are removed more-or-less uniformly throughout the stand to achieve desired stand structural characteristics.

Other Definitions

Biofuels: Any woody biomass used as a feedstock for bioenergy or the development of biofuels.

Salvage harvest or cutting: The removal of trees (dead or otherwise) to inhibit actual or anticipated spread of insects or disease.

Sprout: A shoot originating from dormant or adventitious buds on the stem, branches, or stumps of trees.

Sucker: A shoot or tree arising from adventitious buds on roots or rhizomes. Most commonly used to regenerate aspen.

Thinning: An operation made to reduce stand density in immature groups of trees primarily to recover potential mortality and/or improve growth of residual trees.

Thinning from below: The removal of trees from the lower crown classes to favor those in the upper crown classes.

Thinning from above: The removal of trees from dominant and codominant crown classes in order to favor the best trees of those same crown classes.

Free thinning: The removal of trees to control stand spacing and favor desired trees, using a combination of thinning criteria without regard to crown position.

Logger-select thinning: The removal of trees selected by the logging operator based on guidelines specified in the harvest prescription.

APPENDIX D. SUMMARY OF THEMES FROM OPEN-ENDED QUESTIONS

Many of the themes summarized below have been captured in other locations with additional questions related to herbivory, species regeneration, forest health – insects, diseases, and plants, and site level guidelines.

The main themes, listed in no particular order, in the open-ended questions were:

- Deer have a large impact on the regeneration practices of multiple agencies
 - This includes species planting mix
 - Silvicultural practices
 - Protection methods
- The use of fire and the increased interest in natural regeneration
 - Red pine
 - Jack pine
- Ability to manage and maintain wet forests as forest (black ash & lowland conifers)
 - Insects (Emerald Ash Borer & Eastern Larch Beetle)
 - Road access and maintenance
 - Warmer winters shortening winter operating season
- Managing for multiple objectives
 - Additional silvicultural research in trade-offs
 - Influence of politics and policies
 - Public use and perception
 - Impact of development
- Site level guidelines in young forests especially aspen
 - Snags
 - Coarse woody debris
- Climate change
- Managing older forests

APPENDIX E: POTENTIAL IMPROVEMENTS FOR FUTURE SURVEYS

- The fillable PDF form worked well for the entry of values by survey respondents. In total, 86% of respondents filled out the survey digitally and 14% on paper. While the fillable PDF approach provided an analysis-ready comma-separated data file, the data file contained a large number of columns that needed to be formatted in advance prior to survey delivery.
- Similar to previous surveys, we were unable to document silvicultural practices on non-industrial private lands. We did not attempt to contact consulting foresters in this survey to inquire about these ownerships, as was done with little success in previous surveys. Future surveys could explore additional options for incorporating this ownership group.
- An important piece that was not implicitly asked was about number of acres of artificial regeneration.
- Organizations still had difficulties answering certain questions due high variability among organizations in the way data is collected and stored.