CONSTRAINTS ON PINE REGENERATION IN NORTHERN MINNESOTA:

CAUSES AND POTENTIAL SOLUTIONS

The results of a managers survey and literature review

FINAL REPORT TO THE MFRC NORTH CENTRAL LANDSCAPE COMMITTEE

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EXECUTIVE SUMMARY

In this report, we address questions posed by the Minnesota Forest Resources Council's North Central Landscape Committee (Landscape Committee) related to problems facing pine establishment in northern Minnesota. The report contains two main sections, including a managers' survey and a literature review. Both sections are organized around specific questions posed by the Landscape Committee.

It is apparent from both the Landscape Committee questions and from the results of the managers survey, that the two primary causes for pine regeneration failures are believed to be excessive browsing by white-tailed deer and intense competition from woody shrubs and ground vegetation during critical establishment phases. The latter constraint, excessive competition, is probably manageable given the necessary resources to implement site preparation and follow-up competition control. The former constraint, excessive browsing, is a much less tractable problem.

Although there are solutions for minimizing regeneration failures in the face of high browse pressure, these approaches are costly (area and individual tree fencing) or variable in the effectiveness (i.e., bud capping, chemical treatments). Perhaps the most cost effective solutions, i.e., silvicultural approaches, are the least studied, but may be worthy of greater consideration. Foremost of these include attention to managing for pines within appropriate native plant communities and greater use of natural regeneration and direct seedling, since regeneration establishing from seed appears to be measurably less attractive to browsers. There are a number of additional silvicultural approaches that might be considered, including 1) targeted competition control, as opposed to area wide control, to test the idea that seedlings can better escape browsing by "hiding" within a matrix of vegetation, 2) planting large stock, since such seedlings are more likely to survive and grow out of browse sensitive heights sooner than small stock, and 3) planting and seeding at high densities in an attempt to saturate browsers. The magnitude of the deer browse problem suggests that one approach alone is likely to be variable in effectiveness, but that use of some or all of these measures in combination, along with bud capping or chemical treatment, may increase the probability of successful pine establishment.

INTRODUCTION

Establishment of pines in northern Minnesota continues to be difficult. For example, 110 out of 167 red and jack pine plantations in north central Minnesota failed (defined as requiring multiple attempts at regeneration) between 1990 and 2002 (Minnesota DNR 2007). There are many factors that inhibit establishment of pines; these vary with species and the degree to which they continue to limit establishment. For example, tip weevil and blister rust constrain the establishment of eastern white pine. However, managers have gained an understanding of these problems and have developed silvicultural approaches to successfully circumvent them (Katovich and Mielke 1993; Katovich et al. 2004). Similarly, invasive shoot blights (*Sirococcus conigenus* and *Sphaeropsis sapinea*) appear to be a growing problem for establishing red and jack pines in the region (Nicholls and Ostry 1990; Ostry et al. 1990). However, managers have become more aware of this issue as well as approaches to minimize losses, including ensuring disease free planting stock (Minnesota DNR 2006) and minimizing spatial association between infected overstory pines and regeneration (Palik and Zasada 2003).

There are other constraints on establishment of pine species that have proven more difficult to deal with. Browsing by white-tailed deer is recognized as a widespread problem impacting all pine species. Competition with other vegetation during the establishment and early development phases is also an overarching problem, as is lack of adequate seedbeds for establishment by seed.

While there are other constraints to pine establishment, the general constraints outlined above were identified repeatedly both directly and indirectly in the series of questions developed by members of the Landscape Committee (Appendix 1). Most of these questions were directed at jack and red pines, so we focus primarily on these two species in this report, but also address eastern white pine to some degree.

Our approach for addressing the questions posed by the landscape committee is two-fold. First, we present results of a "managers survey" that was designed specifically to assess experiences of north central Minnesota managers, relative to pine regeneration and establishment issues. Secondly, we review literature, both specific to pines and otherwise, that has some relevance to the questions posed by the Landscape Committee.

MANAGERS SURVEY

The managers survey was designed to assess the real world experiences of managers dealing with pine establishment in Minnesota. The survey was developed by Jason Johnson, then a student at the University of Minnesota, and administered by the Minnesota Forest Resources Council. Our objective here is to summarize the results. This is not a scientific survey, but was designed to get a general sense of experiences. In the survey, the responders were asked to identify the type of agency or organization they represented and their job description. The survey was then divided into sections on eastern white pine, red pine, and jack pine. The same set of questions was asked for each species. The survey was comprehensive in its treatment of pine management issues from early establishment to long-term sustainability on the landscape. In this report we only present results of the survey that are directly relevant to questions posed by the Landscape Committee, specifically relative to pine regeneration and establishment issues.

The survey was sent to 138 individuals from a range of organizations and agencies in Minnesota. These included foresters and wildlife biologist from county, state, and federal agencies, soil and water conservation districts, timber industries, Indian tribes, and independent consulting foresters. The number of actual responders varied depending on the pine species involved and the specific questions, but never exceeded 80. We report the number of responders with different portions of the survey results.

Survey Results

Responder Employer and Job Description

Seventy-nine responders identified their category of employer (Table 1). Nearly one-half identified the State of Minnesota as their employer, followed by county government, and self-employed. No federal managers responded to the survey. Eighty responders identified their job type (Table 2). Nearly one-half were foresters, followed by wildlife biologists, and consultants.

Table 1. Survey respondent employers.

Federal Government	0	0%
State Government	38	48%
Higher Education/Research Institution	4	5%
County Government	20	25%
Municipality	1	1%
Private Industry	4	5%
Self Employed	9	11%
Other	3	4%
Total	79	100%

Table 2. Survey respondent job descriptions.

Forester	37	46%
Wildlife Biologist	23	29%
Educator/Researcher	1	1%
Soil Scientist	0	0%
Natural Resources Consultant	8	10%
Other	11	14%
Total	80	100%

Are Pines Being Managed in the Right Places?

For all three species, most respondents reported that their experiences with pine management occurred in three ecological sections (and a variety of subsections within these). Around 50% worked in section 212n, 16% in section 212m, and 14% in section 212k. Respondents were asked to identify the Native Plant Communities in which they manage the three species of pines. We present these results below (Figures 1-3), separately by species, as they have relevance to two questions raised by the Landscape Committee, specifically,

- *How to select the right species for the site while maintaining a return?*
- *What are site selection criteria?*

Figure 1. Native plant communities with eastern white pine management.

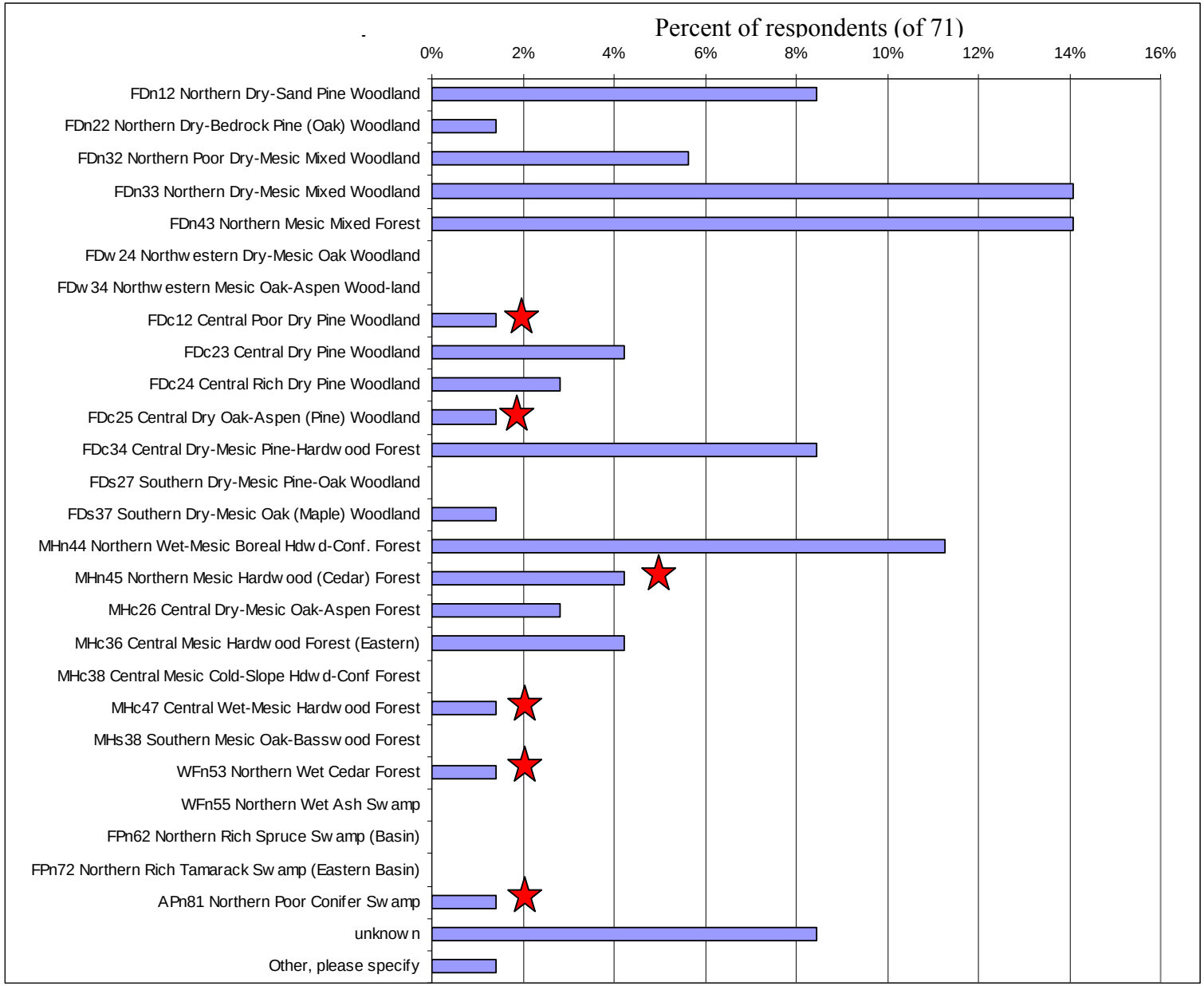


Figure 2. Native plant communities with red pine management.

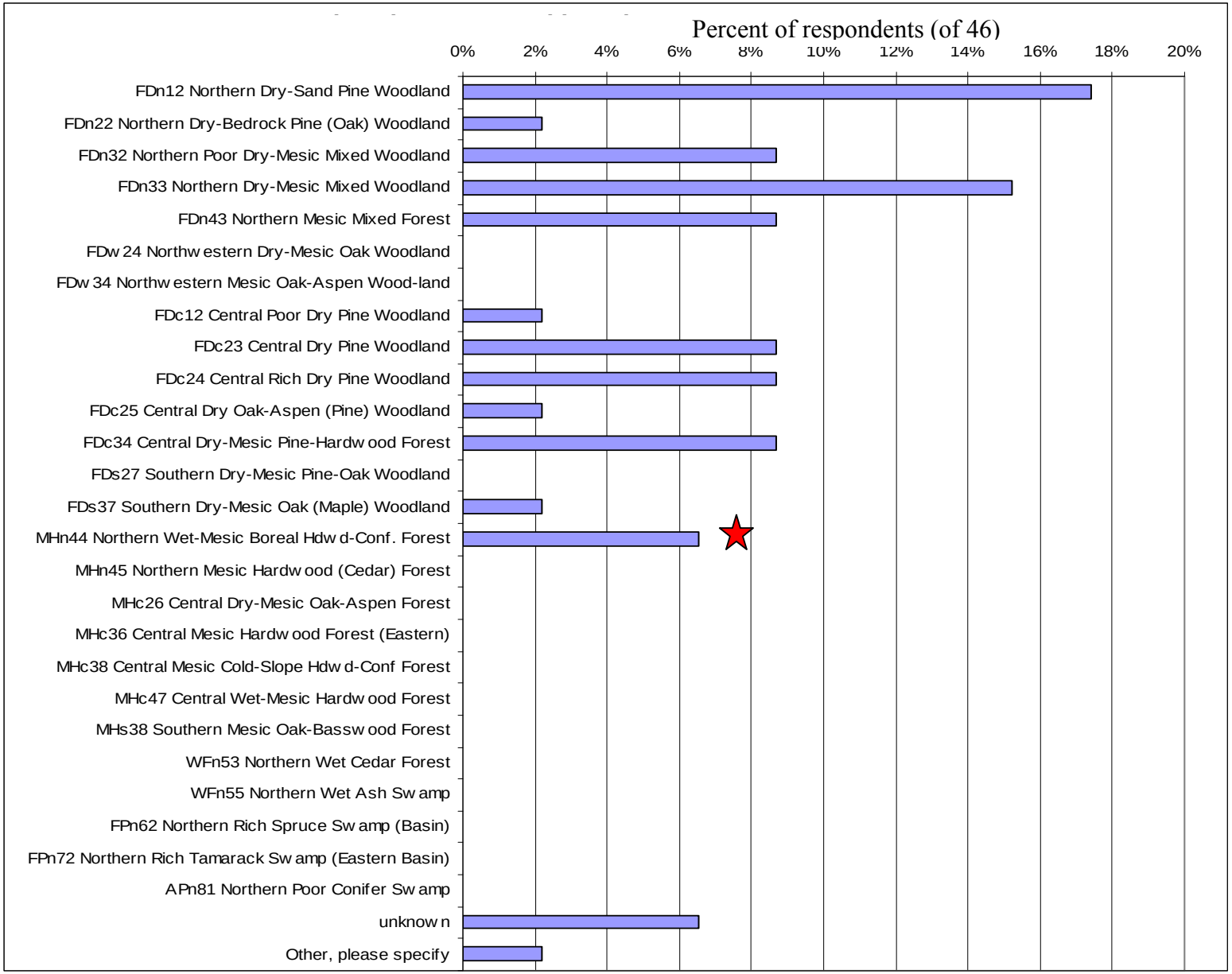
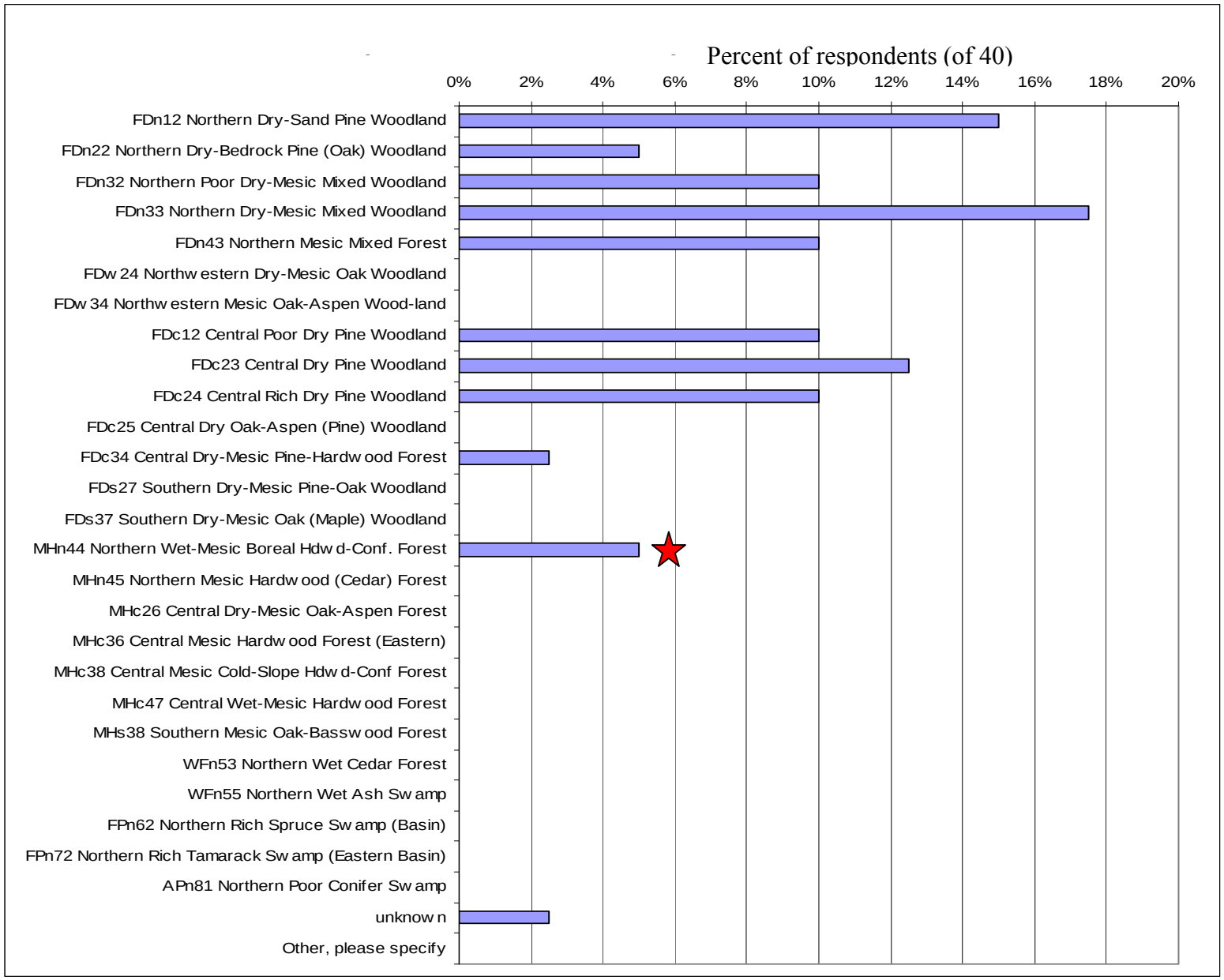


Figure 3. Native plant communities with jack pine management.



Site selection criteria and *matching species to sites* should at a minimum involve ensuring that specific native plant communities are appropriate for the species in question. Overall, the results indicate that pines are being managed in native plant communities where each species occurred in at least moderate abundance during some successional phase; most white pine management is occurring in FDn33, FDn43, and MHn44. Most red pine management is occurring in FDn12 and FDn33. Most jack pine management is occurring in FDn12, FDn33, and FDc23. A possible problem is with MHn44; white pine was abundant only in the MHn44b subtype of this system.

There are a few instances were managers may have in the past or continue to manage for pines on sites not well suited for the species in question. These are indicated by red stars on the figures. The problem seems to be greatest with white pine. There are a few other instances where managing for a particular pine species in abundance might be questionable. The species in question may occur naturally in a particular native plant community, but generally not with any abundance. Managing for jack pine on FDn43 is an example of this.

The DNR Swat Team report (Minnesota DNR 2007) also pointed out that jack pine planting failures were elevated in central floristic region communities, specifically FDc12, FDc23, FDc24 and FDc34. The first three plant communities are naturally woodland systems and although they contained jack pine historically, they may present difficulties for pine establishment due to high abundance of grasses and brush after harvest. The survey suggests that jack pine is being managed to some degree in these problem systems.

Constraints on Establishing Pines

Managers were asked to identify the constraints they faced in trying to regenerate and establish pines. Separate questions addressed natural regeneration and artificial regeneration including both planting and direct seeding. The results are summarized in the following figures (Figures 4-12). All the figures have the same general structure. Managers were asked to rate a suite of potential inhibiting factors as having a strong, moderate, small, or no effect on establishment. These survey results have relevance to addressing the following Landscape Committee question:

- *What are the common factors to jack and red pine plantation failures across the N.C. Landscape?*

The results of these survey questions were generally consistent among the three species. Browsing by deer was identified as the most important constraint on natural pine regeneration, as well as regeneration from planted seedlings. Availability of appropriate seedbeds ranked consistently high as a constraint on regenerating pines naturally and with direct seeding. Competing vegetation, especially woody vegetation was seen as a consistently important constraint for natural regeneration and artificial regeneration with planting and seeding. Availability of seed sources was identified as an important constraint only for regeneration of eastern white pine. Browsing by deer also was identified as the primary constraint on sustaining all three pines species after the initial regeneration period (results not shown).

Figure 4. Factors inhibiting natural regeneration of eastern white pine. Colored horizontal bars reflect the percentage of respondents rating a factor as having a strong, moderate, small, or no effect. (38 respondents)

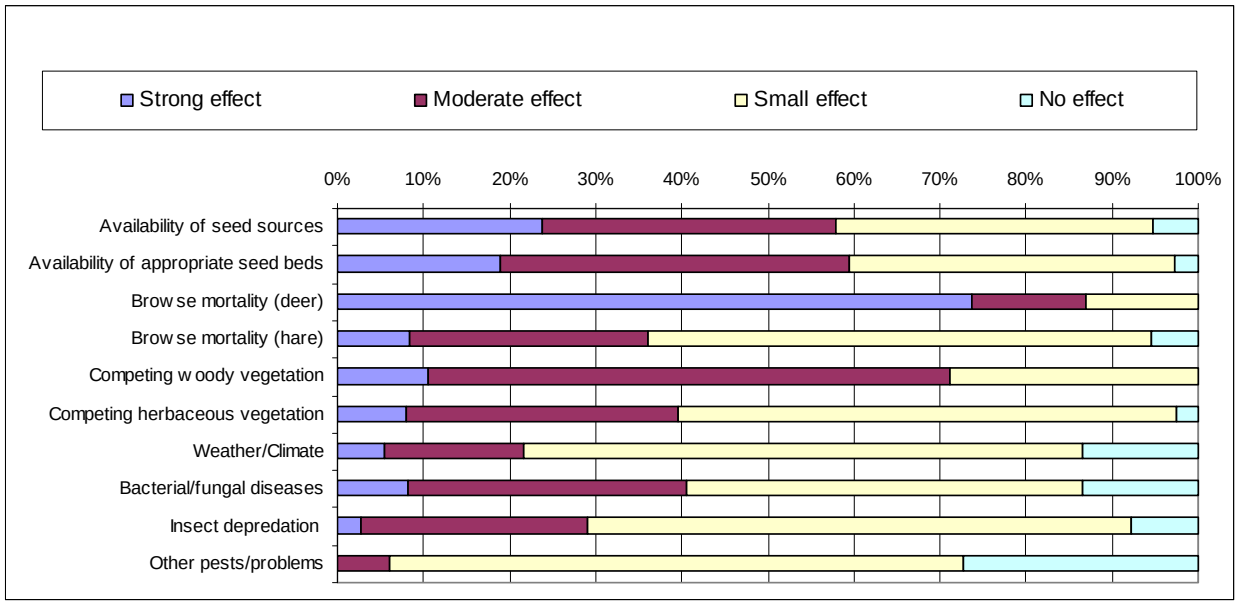


Figure 5. Factors inhibiting planting success of eastern white pine. Colored horizontal bars reflect the percentage of respondents rating a factor as having a strong, moderate, small, or no effect. (36 respondents)

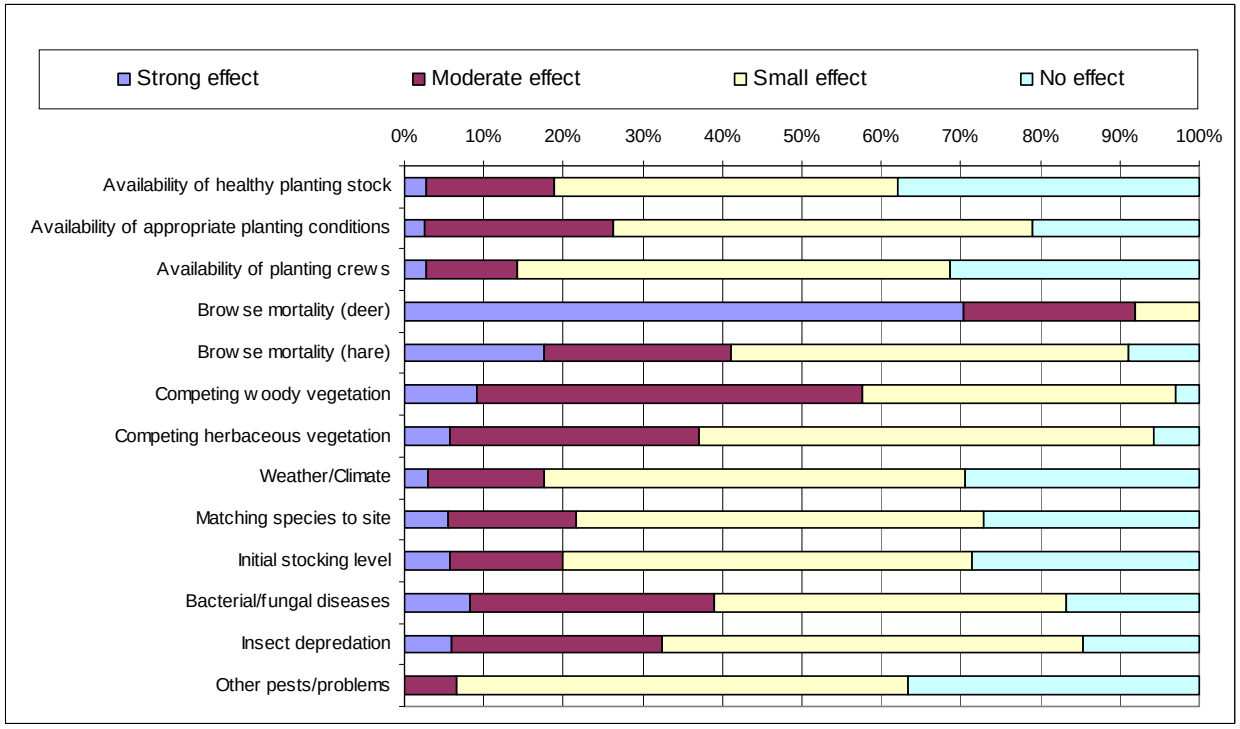


Figure 6. Factors inhibiting direct seeding success of eastern white pine. Colored horizontal bars reflect the percentage of respondents rating a factor as having a strong, moderate, small, or no effect. (28 respondents)

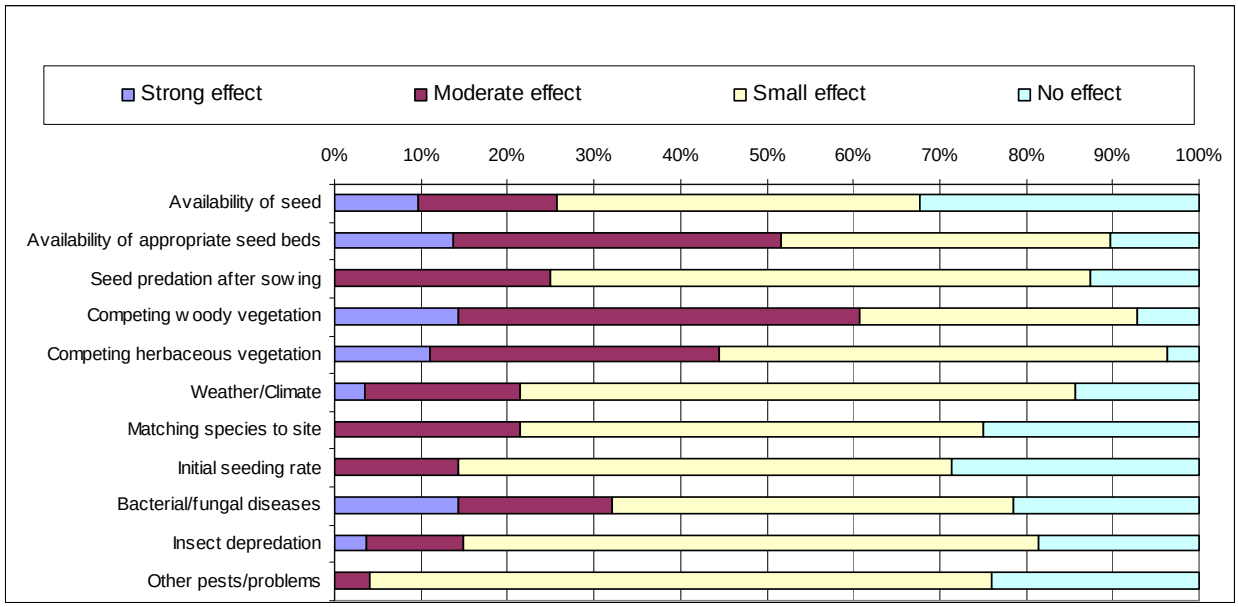


Figure 7. Factors inhibiting natural regeneration of red pine. Colored horizontal bars reflect the percentage of respondents rating a factor as having a strong, moderate, small, or no effect. (24 respondents)

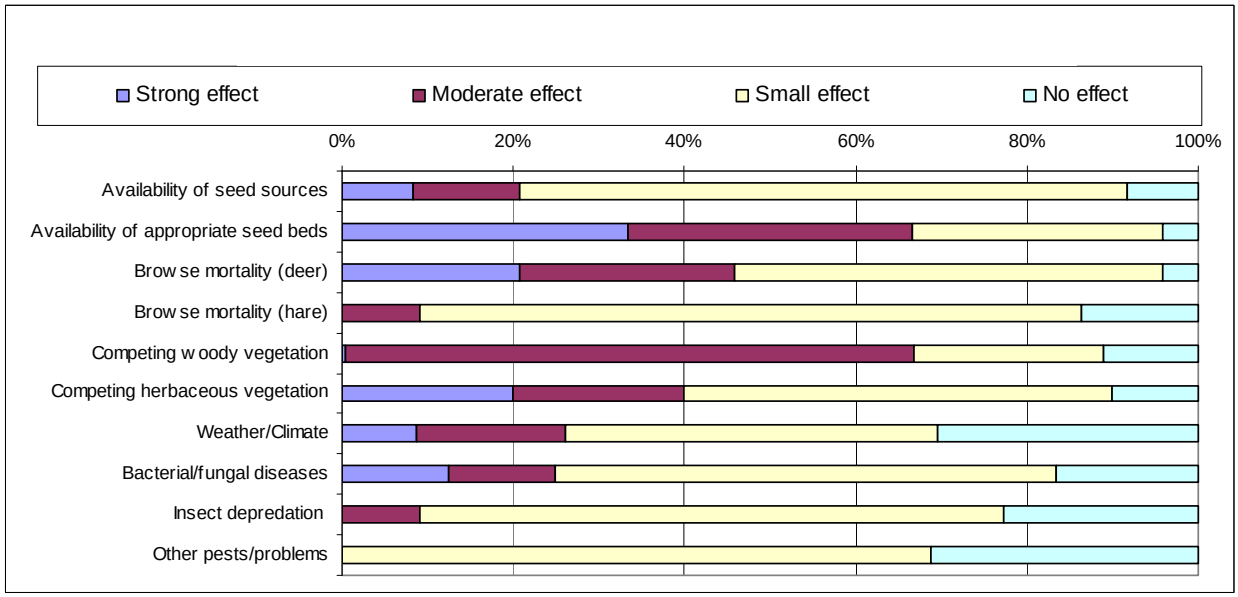


Figure 8. Factors inhibiting planting success of red pine. Colored horizontal bars reflect the percentage of respondents rating a factor as having a strong, moderate, small, or no effect. (24 respondents)

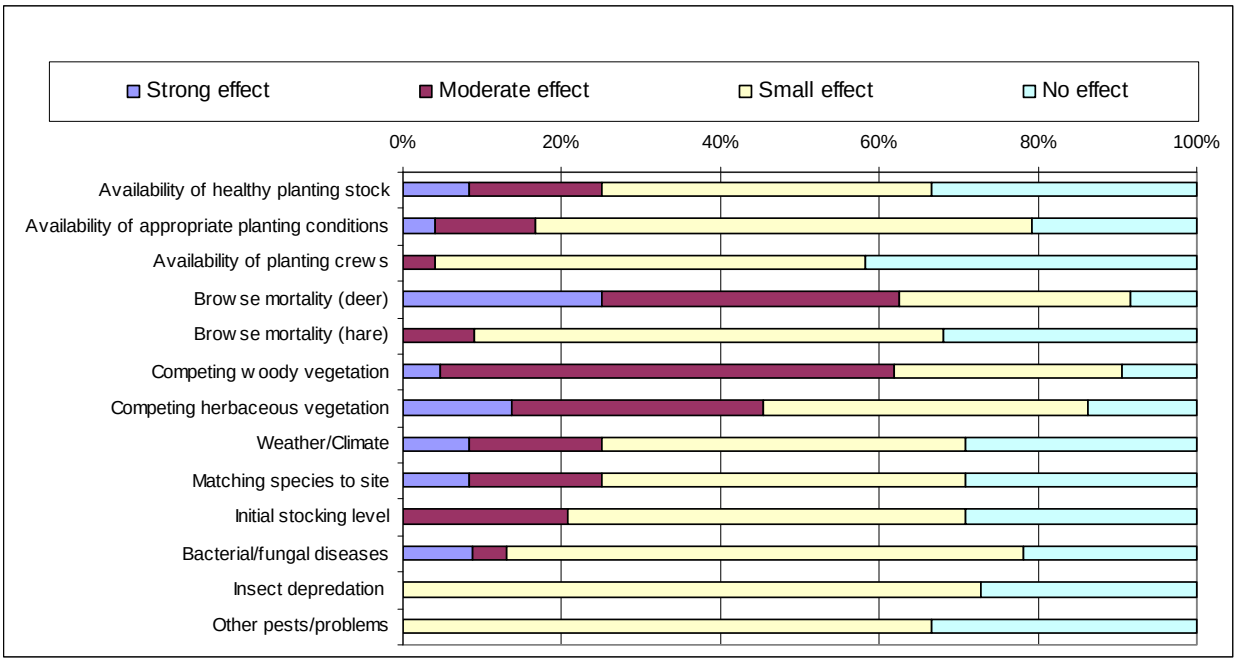


Figure 9. Factors inhibiting direct seeding success of red pine. Colored horizontal bars reflect the percentage of respondents rating a factor as having a strong, moderate, small, or no effect. (17 respondents)

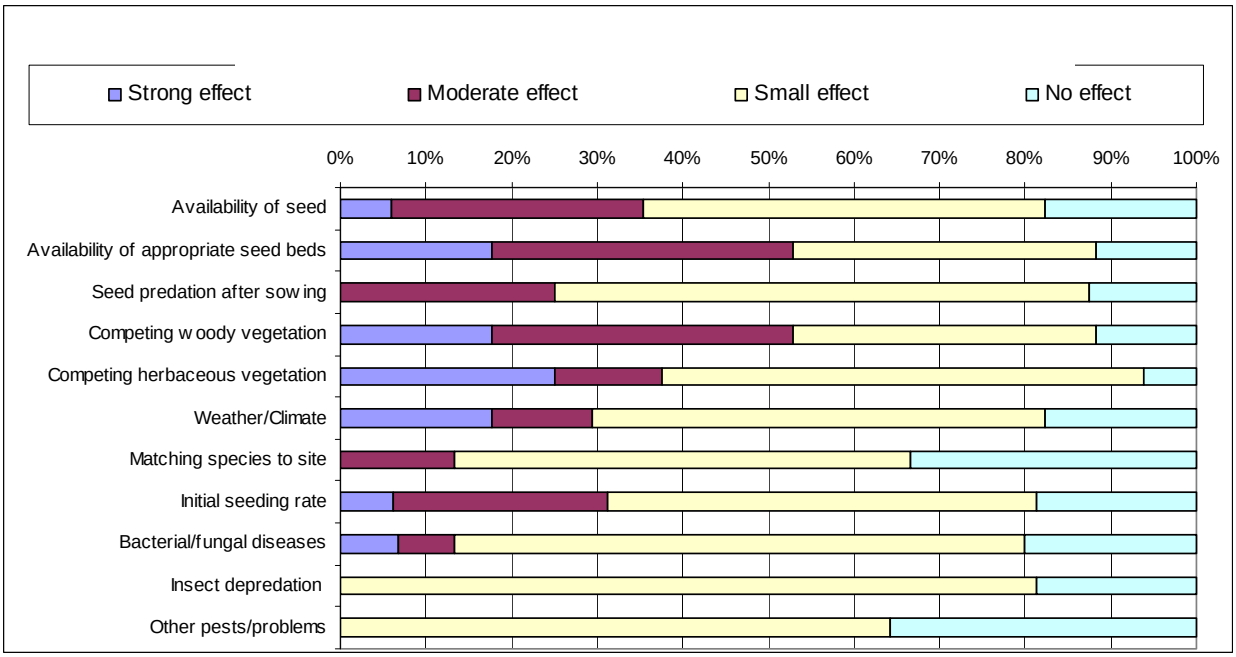


Figure 10. Factors inhibiting natural regeneration of jack pine. Colored horizontal bars reflect the percentage of respondents rating a factor as having a strong, moderate, small, or no effect. (19 respondents)

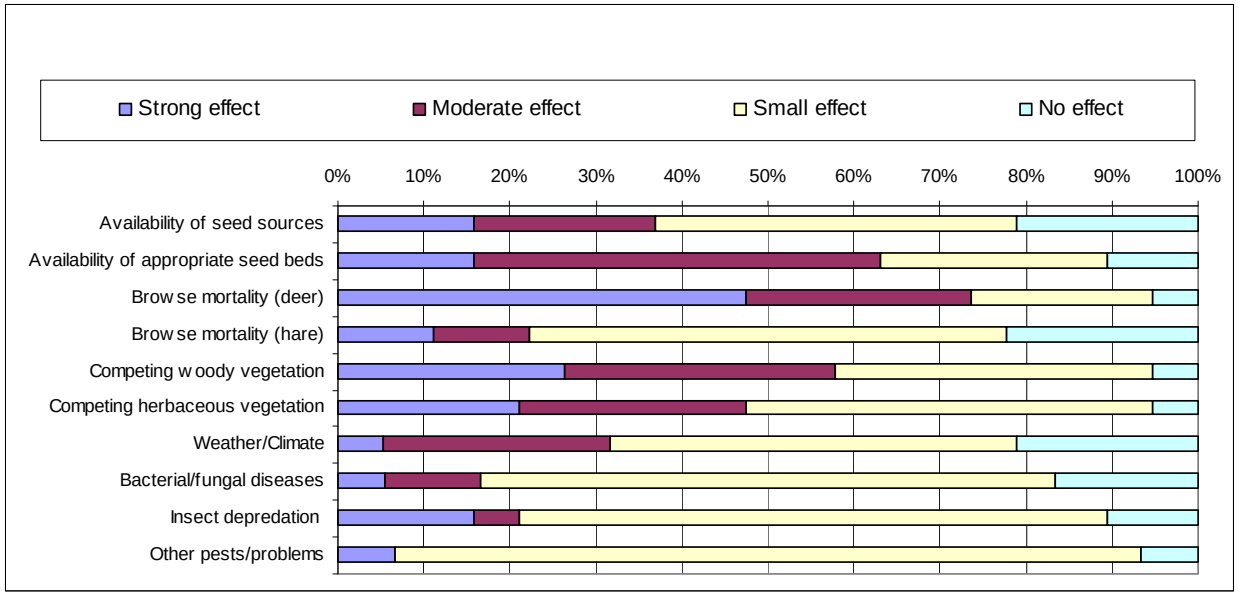


Figure 11. Factors inhibiting planting success of jack pine. Colored horizontal bars reflect the percentage of respondents rating a factor as having a strong, moderate, small, or no effect. (19 respondents)

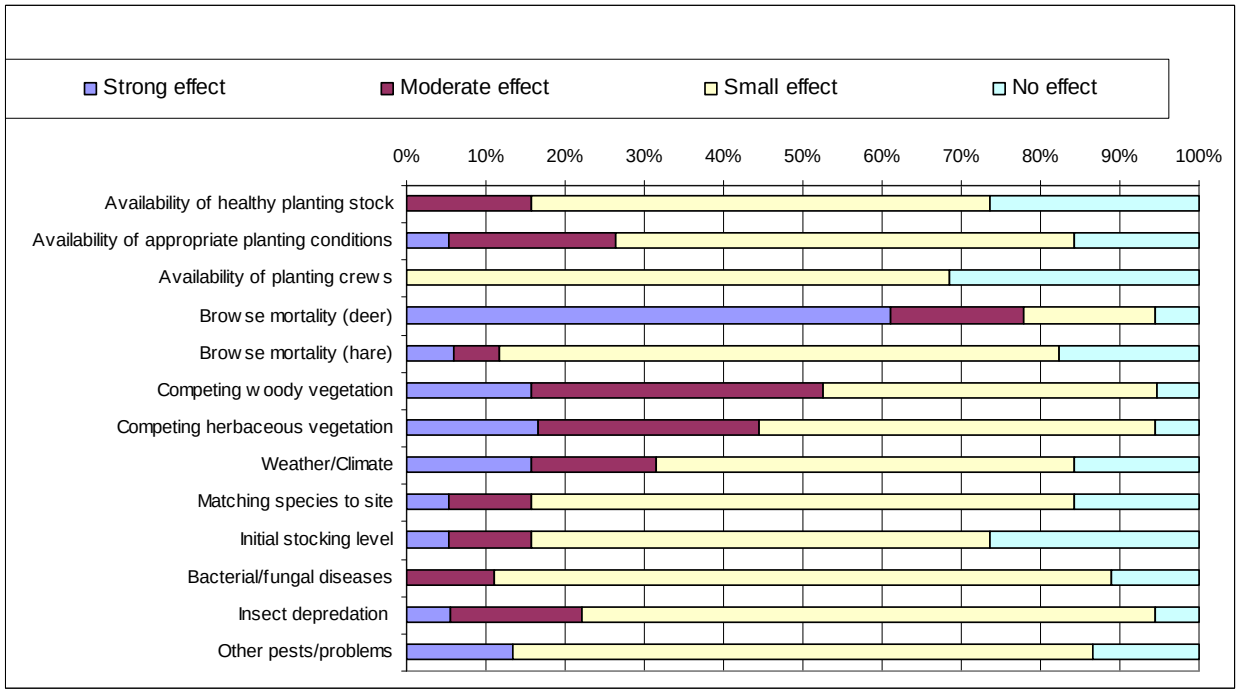
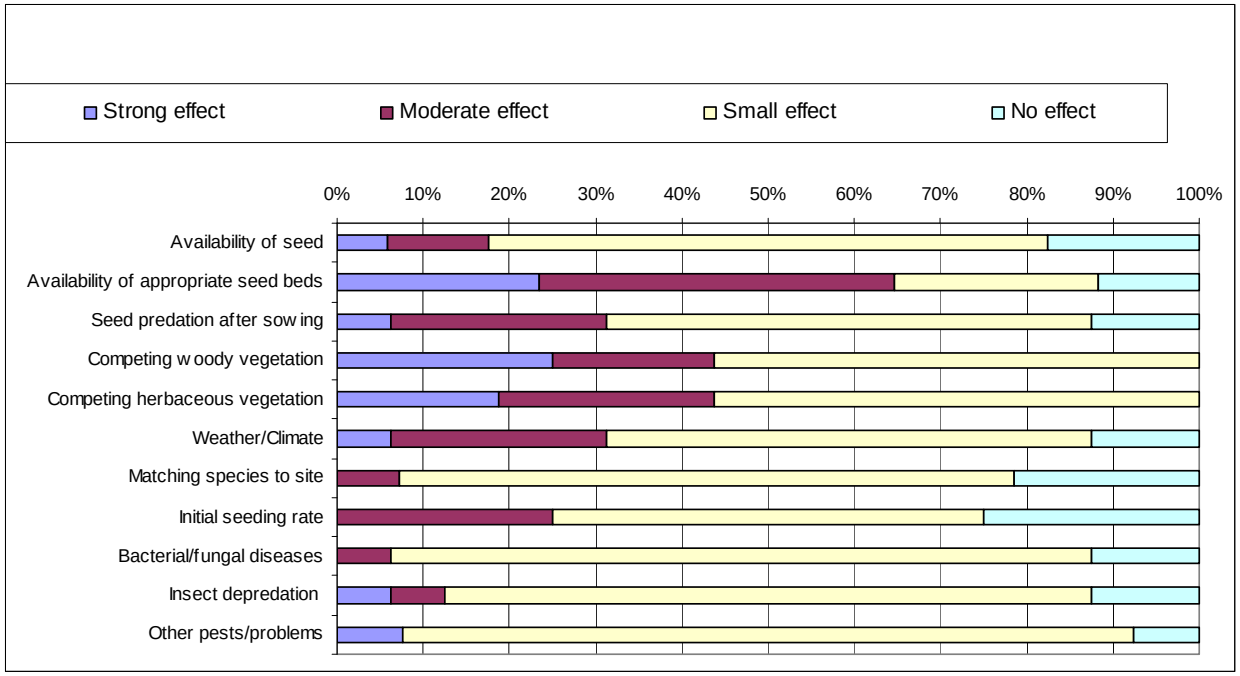


Figure 12. Factors inhibiting direct seeding success of jack pine. Colored horizontal bars reflect the percentage of respondents rating a factor as having a strong, moderate, small, or no effect. (17 respondents)



Referring back to the Landscape Committee question, the *common factors* leading to failure of pine establishment in the north central region, as identified by the survey respondents, included deer browsing and competing vegetation, and for seed establishment, availability of seedbeds.

The Landscape Committee also asked the following question:

- *What % of browsing is due to deer? Other species?*

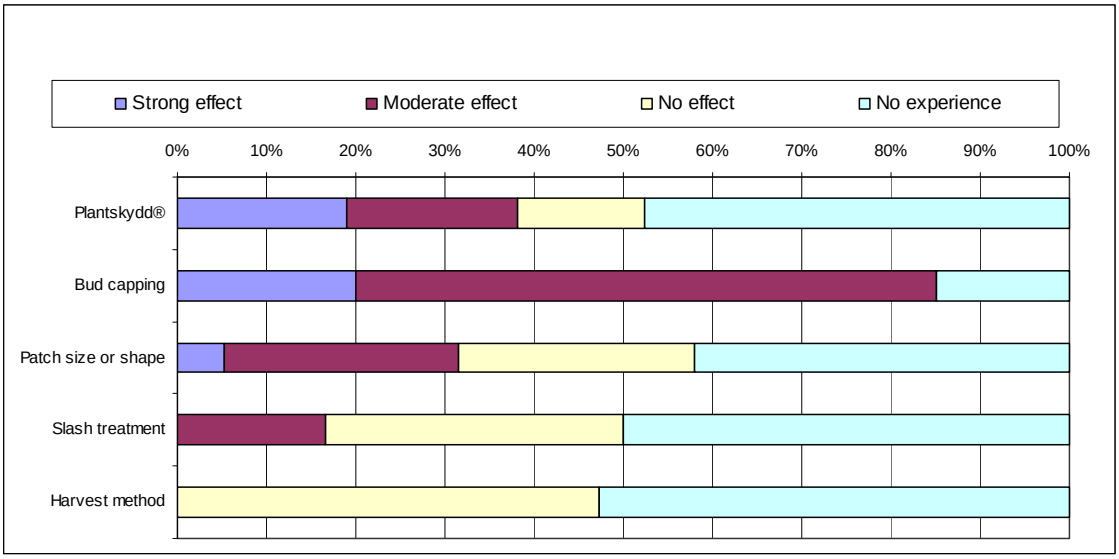
The survey results for all three species (Figures 4-12) suggest that managers believe that browse damage on pines is largely the result of deer, with little attributed to hare.

Success of Animal Deterrent Measures

Managers were asked to rate effectiveness of several animal deterrent measures (Figure 13). This survey question has relevance to the following Landscape Committee questions:

- *How do we protect our seedlings?*
- *How effective is PlantSkydd, bud capping, large patches, at reducing browsing?*

Figure 13. Rating of animal deterrent measures. Colored horizontal bars reflect the percentage of respondents believing that a measure has a strong, moderate, or no effect on deterring damage. (21 respondents)



The survey results suggest that only about 50% of managers have experience with manipulation of slash or harvest methods as deterrents to animal damage. Of those with this experience, all or most feel that these approaches have no effect. Similarly, about 42% of managers have no experience with manipulation of harvest patch size or shape as a deterrent to animal damage. Of those with this experience, almost half find it has no effect, with the remainder finding it has at least a moderate effect. Most managers do have experience with bud capping as a deterrent and find it at least moderately effective, with 20% finding that it has a strong effect at deterring damage. Finally, just over half of the responders had experience using Plantskydd as a deterrent. Of these, most find it at least moderately effective, with nearly 20% finding that it has a strong effect at deterring animal damage.

LITERATURE REVIEW

In this section we present results of a literature review that was conducted in a way that addressed many of the Landscape Committee questions. For this exercise, we examined literature on native pines in Minnesota and the Great Lakes region when it was available. However, we also relied heavily on relevant research and reports from other regions and for other species. The latter was necessary, as pertinent research specifically focusing on red and jack pines in Minnesota was often not available for the specific questions posed by the Landscape Committee.

Browsing by White-tailed Deer

Background Information Related to the Issue

Browse damage and mortality of plants from deer is a widespread problem (Rooney 2001; Côté et al. 2004). There are well-documented examples of impacts to tree regeneration (Horsley et al.

2003; Rooney and Waller 2003) and plant community composition (Russell et al. 2001; Tremblay 2005) from the Great Lakes region and beyond. Specifically, white-tailed deer damage to pine establishment in the Great Lakes region is a large and growing concern (Ross et al. 1970; Sauerman 1992). Deer browsing is rated as the number one constraint to successful establishment of all three pine species in Minnesota (managers survey in this report).

While superficially the extent of browsing would seem to be directly related to deer densities, the actual probability of browsing and resultant damage is related to a complex interaction of factors including deer densities, browse availability, browse quality, preferred browse accessibility, and landscape context. This relates directly to a key question posed by the Landscape Committee:

- *Is deer browsing of seedlings a product of a high deer population?*

The answer to this is yes, but note there is more to this answer than just high deer densities. In this vein, Marquis et al. (1992) talked about the distinction between deer density and deer impact. Deer impact (Figure 14) on regeneration might be moderately high, even at relatively low deer densities, if deer food quality or availability is low. Similarly, deer impacts to regeneration might be moderate, even at high deer densities, if deer alternate food availability or quality is high. Deer impact depends on a number of factors including size of seedlings, quality and abundance of alternative food, ability of deer to find seedlings, density of seedlings, nutrient content of seedlings and soil, hiding cover, and amount of edge (Reimoser 2003).

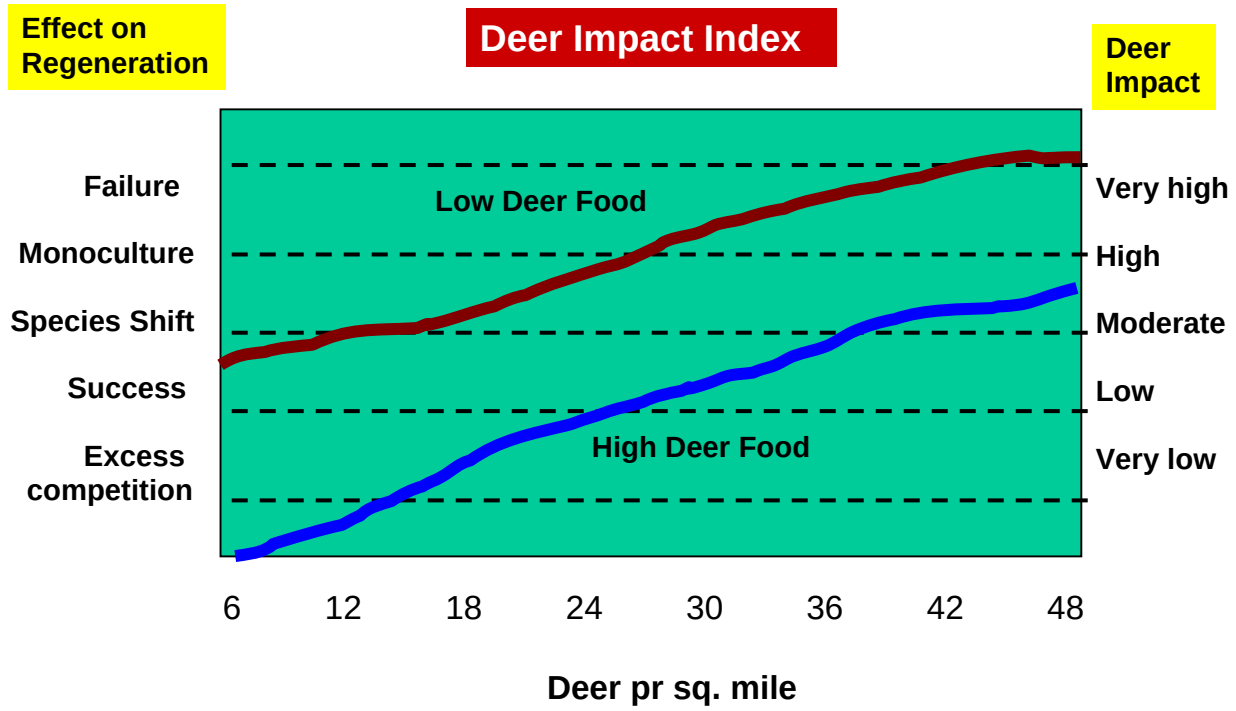


Figure 14. Deer impact index and its effects on tree regeneration. Adapted from Marquis et al. (1992).

Discussion of factors influencing deer population densities is beyond the scope of this report except to note that that higher deer densities are generally problematic to successful tree establishment, but the magnitude of the problem depends on the other factors mentioned above. We review aspects of these interacting factors below in the context of the questions raised by the Landscape Committee.

Attractiveness of Pine Seedlings

Committee members asked the following questions, all of which relate to the attractiveness of pine seedlings to deer.

- *What causes deer to seek out seedlings when the deer population is high?*
- *Why do deer browse on pine seedlings when they have a relatively low nutritional value compared to other available food sources?*
- *What is the measurable difference in deer browse damage between nursery stock and natural regeneration? Is there any difference between nurseries or ages of stock? Can fertilization rates be modified to reduce attractiveness?*

Published literature suggests that the answers to these questions are related at least partially to nutritional status and morphology of planted seedlings, as well at the attractiveness, abundance, and stature of alternative browse species on a planting site.

<u>Plant Nutritional Status</u>

The probability of browsing on a specific plant species is a function of the nutritional quality of the plant, specifically the nitrogen concentration of plant tissue (Gill 1992). It has been demonstrated repeatedly that plants having high tissue nitrogen concentration are more likely to be browsed (George and Powell 1977; Crouch and Radwan 1981; Close et al. 2004; Côté et al. 2004; Miller et al. 2007). For example, an experiment in Sweden showed increased use of plants in nitrogen fertilized plots by two prime herbivores (moose and hares). Plot fertilization significantly improved tissue quality of browse species (including Scots pine, *Pinus sylvestris*) by increasing nitrogen concentration (Ball et al. 2000).

Researchers working with eucalypt seedlings in Tasmania have demonstrated that seedlings receiving high rates of fertilization in the nursery were browsed more than seedlings receiving lower rates of fertilization (Miller et al. 2007). They suggest that modifying nursery fertilization regimes to reduce the chemical attractiveness of seedlings (i.e., lower nitrogen concentrations) to browsers might be one approach to reducing browsing losses. However, this is likely to be effective only when browsing pressure is not extreme.

While fertilization of forest sites to enhance pine growth is not a widespread practice, different types of seedlings do vary in nitrogen status and hence their attractiveness to deer. Naturally regenerated pine seedlings are often browsed less than nursery grown seedlings (Reimoser and Gossow 1996; Bergstrom and Bergqvist 1997, 1999; Bergquist 1998), ostensible due to lower nitrogen concentration in their tissues (Close et al. 2004). However, both naturally regenerated and planted seedlings can have increased nitrogen concentration due to site status. Sites higher

in soil nitrogen availability may be more prone to browsing (Côté et al. 2004). This suggests that planting native pines in appropriate native plant communities is an important consideration. Planting pines, particularly jack and red pines, on more fertile sites than they naturally occur may exacerbate the browsing problem if foliage nitrogen levels are elevated as a result of higher site quality.

Size and Morphology of Planted Seedlings

Given similar site conditions, seedlings of differing morphology (e.g., 1-year-old and 2-year-old containerized and 2-year-old bare-root seedlings) may have different levels of attractiveness to browsers. For example, in an experiment using Scots pine (*Pinus sylvestris)* and Norway spruce (*Picea abies*), two-year-old containerized seedlings were browsed more than the one-year-old containerized seedlings and two-year-old containerized seedlings were browsed more than two-year-old bare-rooted stock. Containerized seedlings are considerably taller and larger in diameter than similar aged bare-root seedlings, and two-year-old seedlings had greater diameter than one-year-old seedlings (Bergstrom and Bergqvist. 1999). Larger seedlings may be more accessible to browsers during periods of heavy snow cover. Alternatively, larger size may reflect higher seedling vigor (i.e., more nutritious), or simply provide more nutrition per amount of energy expended to find the seedling.

However, large seedlings, because they are more vigorous, may be able to successfully recovery from browse damage and grow out of browse susceptible heights more rapidly than small seedlings. In a study that examined survival and growth of Douglas-fir in the face of black-tailed deer browsing, five-year survival, height, and diameter did not differ between browse protected (using a variety of measures) and unprotected seedlings, despite the latter suffering substantial browsing (Gourley et al. 1990). The authors attributed the results to planting large seedlings (3-0, 25 inches tall).

Abundance and Attractiveness of Surrounding Vegetation

Seedlings may become more or less attractive to browsers depending on the vegetation matrix they are planted in or growing in. In general, studies show that conifer seedlings have a lower probability of being browsed if they are surrounded by other vegetation (Welch et al. 1991; Roth and Newton 1996; Bergquist et al. 2003; Côté et al. 2004).

Height of planted seedlings, relative to surrounding vegetation, appears to influence browsing probability. In a detailed study examining browsing of eucalyptus, Miller et al. (2007) found that the relative quality, abundance, and height of neighboring vegetation all influenced the probability that target seedlings would be browsed. Seedlings were browsed more often if they grew with vegetation that was of low palatability, or low abundance, and was short. In such an environment, browsers are maximizing their foraging efficiency by focusing on tree seedlings of higher nutritional quality and that are easier to find.

Work on *Pinus radiata* indicates that browsing by mammalian herbivores depends on palatability and stature of surrounding vegetation (Pietrzylowski et al. 2003). In this study, browsing was most frequent when seedlings were grown within a matrix of short stature, high palatability

vegetation; browsing was intermediate with high palatability, tall vegetation; and was lowest with low palatability, tall vegetation. Browsing was increased within short vegetation, even when it was of low palatability.

In research focusing on eastern white pine in Minnesota, results indicate that visual obstruction of seedlings by surrounding vegetation, and a shorter terminal leader height (than the average height of surrounding understory vegetation) reduced browsing (Saunders and Puettmann 1999). However, in this same research seedlings had a higher probability of being browsed if they were growing in close proximity to dense patches of *Rubus* sp., which are highly preferred browse. The suggestion from this work was that managers should promote dense and vertically diverse understory vegetation within the matrix of the planting site, but devoid of *Rubus* sp.

Attractiveness: Synthesis

While regenerating intolerant jack pine and red pine within a dense matrix of taller vegetation will not be effective, the above results do at least suggest that a causal factor in red and jack pine browsing damage is that the seedlings are likely easy for deer to find on the typical planting site. Site preparation techniques that reduce herbaceous and low woody vegetation, while important for minimizing competition with young seedlings, likely exacerbate deer browse problems.

Higher nitrogen status of the typical nursery-grown seedling likely increases the attractiveness of the seedlings. Also, the probability of being found and browsed may be increased if the seedlings are older or containerized, because they are larger (but only up to a point). Maintaining high seedling vigor is likely an important factor in mitigating browsing losses. Thus, planting larger than typical seedlings and maintaining their vigor through competition control in their immediate vicinity (but not stand-wide), may allow seedlings to recover from browsing and more rapidly grow out of browse sensitive height.

Landscape Configuration

The following question was posed by the Landscape Committee.

- *Are larger sites better because they have less edge effect per acre?*

This question is related to factors operating at scales beyond seedlings and associated vegetation; factors like amount of edge, and proximity to winter cover. White-tailed deer are classic edge species, having an increased presence along edges (Lidicker 2004). As such, deer damage may be higher with increased edge, as would be found when small planting sites are juxtaposed with small patches of mature forest. This effect has been examined within the context of deer penetrating into mature forest from the edge in order to browse seedlings (e.g., Cadenasso and Pickett 2000, Côté et al. 2004), but not extensively from the perspective of deer penetrating into open pine planting sites from edge habitat. However, a study of tree species invasion in a Minnesota old field in close proximity to intact forest documented that deer herbivory limited tree establishment (Inouye et al. 1994). Moreover, in a study of jack pine establishment success in northeastern Minnesota, white-tailed deer browsing was noted as “frequent” on seedlings

planted in cut strips that alternated with leave strips, with the suggestion that narrow cut strips (<200 feet wide) are problematic because of increased edge (Alm et al. 1978).

Also, in a landscape context, pine sites in closer proximity to winter conifer cover may experience higher deer densities, and as a result higher potential for browsing (Lebouton et al. 2005), although the published evidence for this is limited and not specific to regenerating pine species.

Deer Population Size

Committee members asked several questions related to threshold deer population densities.

- *At what population level will deer browsing of seedlings become a non-factor in plantation establishment?*
- *What is the minimum deer herd population levels that would be considered sustainable for wildlife purposes, as well as for forest management purposes?*
- *What is the level of deer population at which lethal browsing ceases to be a problem in the X area on Y species?*

A review of the factors that influence deer population densities is beyond the scope of this report. Our hope was that there might be some published research that suggested how different population levels impacted pine plantation establishment, particularly in the Great Lakes region. We did not find this work. We did come across some references that address the minimum deer population density, below which deer browse problems on tree seedlings may become less of a problem, but this work largely comes from other forest types. This information has only limited relevance to the questions posed by the Landscape Committee.

For example, research on development of balsam fir advance regeneration in the boreal forest indicates that the threshold for successful fir establishment in mature forest is 39 deer/mi^2 (Tremblay et al. 2007). This is a high number and likely reflects that fact that balsam fir is not a preferred browse species. Research on understory regeneration of Canada yew, eastern hemlock, and white cedar suggest that densities as low as 10 deer/mi^2 may be a critical threshold (Alverson et al. 1988) for sustaining regeneration of these species. In this same work, densities of <5 deer/mi^2 are rated as low, 5-13 deer/mi^2 as medium, and >15 deer/mi^2 as high. A modeling study examining long-term sustainability of white pine in Minnesota used these density ratings and determined that deer densities exceeding the high threshold prevented red and white pine establishment on regenerating jack pine sites (Tester et al. 1997). In an unpublished case study conducted by the MN DNR (Minnesota DNR 2001), bud capping and repellents appeared to be effective at population densities at or below 12 deer/mi^2.

Solutions to Browse Problems

Several of the Landscape Committee questions focused on potential solutions to the deer browsing problem as related to pine establishment. These questions generally seemed to be posed with the realization that widespread reduction in population densities was not likely, or at

least would be difficult to achieve. Rather, the questions were aimed at addressing ways to ensure some pine establishment in the face of high deer numbers. For example:

- *How do we protect our seedlings?*
- *Repellants that work?*
- *Repellants that do not work?*
- *What kind of structures can we put on them to prevent browse that are cost effective?*
- *How effective is PlantSkydd, bud capping, large patches, etc. at reducing lethal browsing? Is it cost effective?*
- *What is the effectiveness, and cost effectiveness of various protection measures (i.e. bud caps, repellants, fences) based on various deer herd populations?*

The published literature offers several potential approaches for mitigating the deer browse problem, many of which are applicable to pine plantation establishment and the questions posed above.

Physical Barriers

Deterrents can take the form of physical barriers to browsing. Physical barriers include fencing of regeneration areas; fencing, mesh, or tubes around individual seedlings; leader guards; and bud capping. All have merits and limitations. Fencing around regeneration areas is expensive to erect and maintain, but generally effective for small planting areas if they are high enough and properly maintained. Plastic tubes, wire fencing, leader guards, and netting around individual seedlings are also expensive but can be effective (Lavsund 1987; Ward et al. 2002). However, there is research evidence on Douglas-fir demonstrating that individual tree tubes, leader guards, and netting can be detrimental to tree survival due to physical injury (Gourley et al. 1990). Moreover, the cost associated with these approaches is likely prohibitive in many situations. For example, the Chequamegon-Nicolet National Forest Regeneration Handbook for 2004-2008 estimates costs of materials and installation of $1.30 per tree and $5.20 per tree for mesh and tubex barriers, respectively (USDA Forest Service 2004).

Bud capping, typically with paper, is widely used and effective at moderate deer densities. However, this approach may be no more effective than other methods. For example, a study using Douglas-fir and black tailed deer found no differences in browse frequency over two years, or survival over five years, among various protection methods, including paper bud capping, tubes, netting, leader guards, and Deer Away repellent (Gourley et al. 1990). All offered relatively good protection from browsing.

An unpublished case study in Minnesota evaluating bud capping and chemical repellents on jack and red pine found that that bud capping treatments (traditional paper, self-sticking paper) averaged 14% damage compared to 23-70% damage for unprotected seedlings, and 4-9% damage for TreeGuard and PlantSkydd chemical repellents (Berguson, B. 2005. NRRI, unpublished data).

In another unpublished case study from Minnesota (Minnesota DNR 2001), bud capping of white and jack pines was found to be ineffective (0-6% seedlings protected) at a site where deer density

was projected to be 18 deer/mi^2. Conversely, bud capping was found to be 97% effective on white pine at a site where deer densities were projected to be 12 deer/mi^2.

Bud capping costs do tend to be reasonable relative to individual barriers. For example, the Chequamegon-Nicolet National Forest Regeneration Handbook estimates costs of materials and installation of bud caps on pines at $167/acre (USDA Forest Service 2004).

Repellents

Repellents are generally economical and can be effective under the right circumstances. Expectations for repellents should be reduction of damage, not elimination (Craven and Hygnstrom 1994). Repellents are classified based on their mode of operation: fear, conditioned aversion, pain, and taste (Beauchamp 1997; Mason 1997)

There have been many studies done on repellent effectiveness and the external factors that influence this. Some studies suggest that repellents have limited value (Bergquist and Orlander 1996; Guorley et al. 1990), but this is determined by the type of repellent used and the external factors at the time of the study. For example, the effectiveness of repellents increases with concentration (Andelt et al. 1992; Baker et al. 1999), but decreases with time since application (Andelt et al. 1992), attractiveness of the plant (Swihart et al. 1991; Wagner and Nolte 2001), deer hunger (Andelt et al. 1992), and amount of rainfall (Sayre and Richmond 1992).

Available evidence suggests that repellents applied directly to plants are more effective than area repellents, that odor-based repellents outperform taste-based repellents, and that fear-inducing repellents have the best performance (Nolte 1998; Nolte et al. 1994; Swihart et al. 1991; Wagner and Nolte 2001). For example, a study on repellents and browsing by black-tailed deer found that fear-based repellents containing decaying animal proteins, such as whole egg solids or blood, were most effective in both winter and spring trials (Trent et al. 2001). Top performing repellents in the fall in order of effectiveness included Deer Away Big Game Repellent powder, Deerbuster's sachet, Bye Deer Sachets, and PlantSkydd (Figure 15). The first two repellents limited the average number of bites per seedlings to near zero over an 11-week period, while the latter two limited the average number of bites to two to three over the same time period. All other repellents tested (taste based, conditioned avoidance, pain) performed substantially less effectively over the 11-week trial (average number of bites per seedlings >5 to 25). Similar results were found in a spring trial.

In a case study of repellents on jack pine in Wisconsin, PlantSkydd and Deer Off (fear-based) were somewhat superior to a variety of other repellents including Tree Guard, Thiram, and Hinder (Christians 2005). Even so, the range in protection was low, from 29% unbrowsed seedlings with PlantSkydd to 17.9% for Tree Guard.

In a case study conducted on pines in Minnesota, bud capping alone, PlantSkydd alone, and bud capping combined with PlantSkydd resulted in similarly high protection of white pine seedlings (97%, 97%, 100%, respectively) over one fall to spring season. In a second trial at a different planting site, PlantSkydd alone resulted in 31% protection of jack and white pines, compared to 6% protection for bud capping and for bud capping combined with PlantSkydd (Minnesota DNR

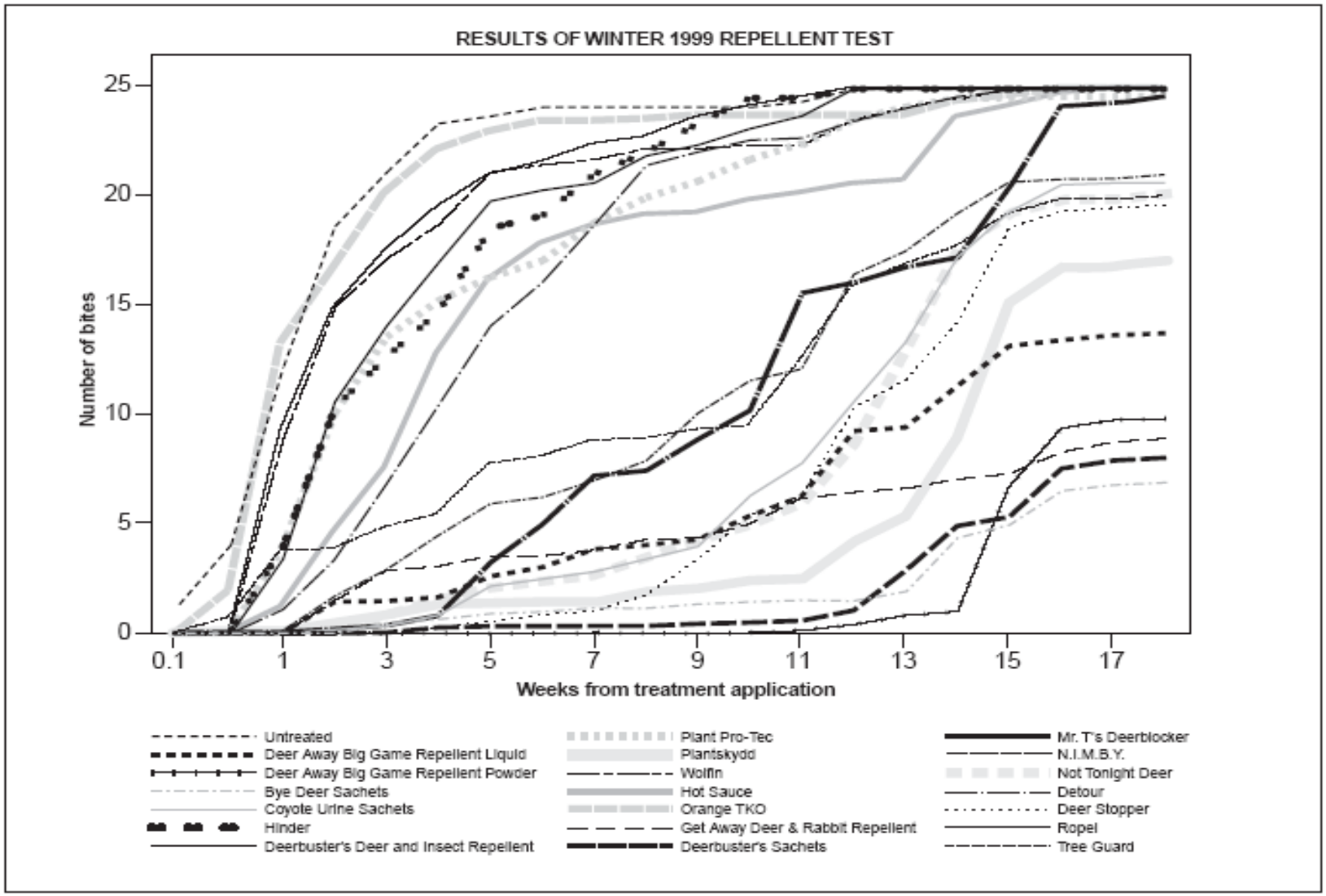


Figure 15. Chemical browse deterrent performance on Douglas-fir. Adapted from Trent et al. 2001.

2001). The difference between the two trials was attributed to differences in deer densities; 12 deer/mi^2 in the first trial versus 18 deer/mi^2 in the second trial. Other chemical repellents including Ropel and Treeguard had somewhat poorer performance at both locations.

In a case study using jack and red pines in Minnesota (Berguson, B. 2005. NRRI, unpublished data), Deer Away was found to be largely ineffective, resulting in 30-60% browsed seedlings, compared to 22-78% browsed seedlings for unprotected seedlings. This result contrasts greatly with the high effectiveness of Deer Away (powder) found with Douglas-fir in the study cited above (Trent et al. 2001). Treeguard and PlantSkydd afforded good protection (9 and 4% average browsed seedlings, respectively). However, TreeGuard appeared to be toxic to pine seedlings, resulting in burning of needles. A similar result has been noted for Deer Away on Douglas-fir seedlings (Gourley et al. 1990).

In a controlled study of black-tailed deer browsing on ponderosa pine and Douglas-fir seedlings, PlantSkydd, Deer Stopper, and Big Game Repellent powder all provided highly effective reduction in browsing for up to 7 weeks (<10% seedlings browsed) and good reduction for up to 14 weeks (<25% browsed) compared to 100% browsing by 5 weeks for untreated seedlings (Nolte 1998).

In general, PlantSkydd seems to fall out as consistently effective, including on pines in Minnesota. Also, chemical repellents tend to be reasonably priced relative to physical barriers. For example, the Chequamegon-Nicolet National Forest Regeneration Handbook estimates costs of materials and application on pines at $187/acre (USDA Forest Service 2004).

Silviculture

Silvicultural practices have some potential to minimize deer browsing damage and mortality in pine plantations. In fact, there appears to be a general trend towards incorporating silvicultural techniques into the toolbox of deer deterrent strategies (e.g., Stout 2005; Tremblay 2005). The following Landscape Committee questions addressed these approaches in a general way.

- *What management techniques can be implemented to improve the success rate of acres that are planted to pine to ensure future pine on the landscape?*
- *What are some alternate silvicultural methods to explore?*

Some of the silvicultural techniques that are suggested as effective in reducing deer browse losses, or that are at least implied based on research, include 1) maintaining slash on site, 2) planting at high seedling densities, 3) planting large seedlings (Duddles and Edge 1999), 4) planting small seedlings, 5) planting seedlings within matrices of other more palatable vegetation (Duddles and Edge 1999; Welch et al. 1988; Roth and Newton 1996), 6) planting seedlings within scarified plots, 7) managing nursery fertilization rates to reduce nutritional quality (Close et al. 2004), 8) plant bare root stock, 9) regenerate naturally. Some of these recommendations are conflicting. Reducing attractiveness of seedlings through use of reduced nitrogen fertilization rates in the nursery will result in lower vigor, smaller seedlings. Such seedlings will be less able to recover from deer damage and will remain in preferred browsing heights for

longer periods of time. These types of conflicting suggestions indicate that there are potentially multiple ways to reduce browsing silviculturally, (e.g., plant larger, nutritionally healthy seedlings, or plant seedlings with lower nitrogen content to make them less attractive to deer). We summarize some of the silvicultural approaches below.

Retaining Slash-A common recommendation to physically discourage deer entrance into a planting area is to leave abundant slash cover to restrict movement. Some studies have found that slash can physically hinder deer browsing (Morgan 1991; Putman 1994). Other studies with various species have failed to detect differences in browsing frequency on sites with and without slash retention (Bergquist and Örlander 1998; Fredericksen et al. 1998; Bergquist et al. 2003). The suggestion from the latter studies is that slash left at levels typically occurring in most harvest sites does not present enough of a physical obstacle to deer to drastically reduce browsing.

High Planting Density-Planting at high densities is recommended as a means of saturating deer with food and allowing a greater proportion of stems to escape browsing (Lyly and Saksa 1992, Martin and Baltzinger 2002, Welch et al. 1991, Reimoser 2003).

Planted Seedling Size-The research literature is a bit conflicting as to how seedling size affects browse probability. Some research suggests that smaller seedlings are browsed less (Bergström and Bergqvist 1999; Pietrzykowski et al. 2003). A presumed explanation for this that if the seedlings are not substantially taller than surrounding ground vegetation they are harder for herbivores to find (Pietrzykowski et al. 2003; Miller et al. 2007). Other research suggests that taller seedlings are browsed less and/or have greater ability to recover from browsing (Newton and Black 1965; Hines and Land 1974; Welch et al. 1991; Saunders and Puettmann 1999; Ward et al. 2002). The latter result is often attributed to the vigor of larger seedlings; that is, larger seedlings are healthy, more competitive, and are able to withstand moderate browsing and grow out of susceptible heights more rapidly than shorter seedlings (Gourley et al. 1990).

Associated Vegetation-Numerous studies show or suggest that tree seedlings surrounded by other vegetation tend to be less heavily browsed than those that are not (Welch et al. 1991; Reimoser and Gossow 1996; Roth and Newton 1996; Bergquest et al. 2003; Miller et al. 2007). The extent that this is true is presumably influenced by the palatability of the surrounding vegetation. Planting near preferred browse species, or in areas with a low abundance of alternative foods, may increase the likelihood that nearby seedlings are browsed (Campbell and Evans 1978; Gill 1992; Saunders and Puettmann 1999; Pietrzykowski et al. 2003). On the other hand, failure to adequately control competing vegetation will likely keep seedlings in susceptible height ranges for longer periods of time, increasing the likelihood of initial and repeated damage from browsing (Caldwell et al. 1995; Saunders and Puettmann 1999).

One particularly compelling study, which argues for controlling competing vegetation, compared the interaction of competition control and browse protection treatments on browse damage, seedling growth and survival (Gourley et al. 1990). Using Douglas-fir seedlings, this study found that seedlings planted on sites where competing ground vegetation had been controlled were significantly larger than seedlings on plots without vegetation control. Moreover, the result was irrespective of deer browse treatment.Unprotected seedlings grew just as well as protected

seedlings, and all seedlings had similarly high survival after five years regardless of protection treatment. The authors attribute this result to the large size of seedlings at planting (3-0; 25 in average height), which resulted in high vigor and ability to recovery from browsing.

One approach that these results suggest is that competing vegetation should be controlled locally around seedlings, for example through spot scalping, but that vegetation in the matrix of the planting site should be allowed to remain as a hiding cover for the planted seedlings.

Naturally Regenerate or Direct Seed-All other factors being similar, naturally regenerated seedlings are measurable less likely to be browsed than nursery grown stock, often because the latter have high nitrogen concentrations in their tissues. The improved nutritional status increases their attractiveness to deer. This situation argues for increased use of natural regeneration of pines and or use of direct seeding.

Landscape Considerations

Several considerations for managing the browse problem apply at scales larger than planting sites. Recommendations include planting after several harsh winters when deer populations may be reduced. Avoid planting sites that are near winter thermal cover (Lebouton et al. 2005) and reducing edge by increasing the size of planting sites. Finally, another approach is to concentrate deer populations in certain portions of the landscape, away from focal planting sites. This might be done by deliberately planting or seeding preferred browse plants, or fertilizing select plantings to increase nutritional attractiveness (Ball et al. 2000), and thus concentrate deer in specific areas. The presumption is that other nearby areas, when tree establishment is desired, will face less browsing pressure.

Summary of Deer Browse Reduction Approaches

It should be evident from the above review that the issue of deer browsing on tree seedlings, pine species included, is complicated. Moreover, strategies for reduction of browse damage are not guaranteed, nor necessarily cost effective. The conclusion we draw from this is that mitigation of the deer browsing problem requires a multi-pronged approach in which a number of measures are taken to decrease the likelihood of complete regeneration failures.

Measures to consider relative to pine management include:

1. Plant at densities higher than normal stocking with the expectation that losses will occur but adequate seedlings will survive to reach less susceptible heights.
2. Apply repellents (fear-based, e.g., PlantSkydd) or bud cap yearly until regeneration is beyond susceptible browse heights.
3. Plant larger than normal, vigorous seedlings.
4. Control competing vegetation around seedlings, but not on an area-wide basis.
5. To the extent possible, allow herbaceous and shrub vegetation to develop in the matrix of a planting site around planted pines, to potentially make locating pines more difficult.
6. Increase planting site size to reduce edge.
7. Consider natural regeneration of pines, which is measurably less attractive to deer.

Establishment from Seed and Competition Control

Several of the Landscape Committee questions related to direct seeding of pines as an alternative to planting. Additionally, several questions were related to the effects of competing vegetation on pine establishment and early growth. We address several of these questions below, largely relying on research from Minnesota or the Lakes States.

Direct Seeding

The Landscape Committee asked the following questions related to seeding:

- *In the NC Landscape, why has direct seeding in clearcuts not been effective?*
- *What other management techniques can be used to establish pine other than planting; and is this a viable option given that most of the seed sources such as white pine have already vanished?*

There has been a substantial amount of research on direct seeding of jack and red pine in the Lake States and similar regions. Much of this research actually shows that direct seeding can be successful, however the requirements are often fairly strict, hence the poor success of seeding in practice.

For example, research has shown the importance of deliberate scarification to expose seedbeds, control early competition, and improve moisture status. Deep scarification (for example with an Athens disk), even after prescribed fire, is important for jack pine establishment from seed, particularly during dry conditions. Soil moisture conditions are improved in the bottom of furrows that occur with deep scarification, which also removes a nutrient leached surface soil layer, exposing a lower layer having higher nutrient concentrations (Cooley 1972). In this study, scarified and seeded plots (seeded at 20,000 seeds/acre) were stocked with 27,000 seedlings/acre after two years (some came from an on-site seed source), compared to 10,000/acre with seeding only, and 8,000/acre with scarification only. Seedlings also grew better in furrows than on the edges of furrows.

Soil moisture condition appears to be a key factor influencing jack pine establishment success with seeding. Early in the last century, it was shown that seeding success of jack pine can be significantly increased if this practice is restricted to sandy sites that have a permanent water table varying within 2 - 5 feet of the surface (Stoeckeler and Sump 1940). The authors contend that this condition is not unusual in the Lake States. This also implies that successful seeding will likely only occur during non-drought conditions. In drought conditions, careful attention to site hydrology becomes more important than in non-drought years. Studies also point to the advantage of covering sown seed with a thin layer of mineral soil as opposed to sowing directly on the surface (Stoeckeler and Sump 1940), presumably to enhance moisture conditions.

In a study in northern Minnesota, Alm et al. (1978) found that scattering cones in the spring following a summer clearcutting and whole tree skidding resulted in seedling establishment of 588-790 seedlings/acre after four years, but this regeneration was highly clumped and the stand was considered understocked. Fall cone scattering resulted in even fewer seedlings (121-

427/acre). These results again point to the importance of deliberate scarification, even after summer logging, for direct seeding success.

Other research demonstrates the importance of different scarification methods for seeding success. In a study comparing seeding success for jack pine, 5th year stocking averaged 11% on logged-only sites, 45% with disk scarification after logging, and 74% with spot scalping (at 468 scalps/acre) (Benzie 1968). The difference was attributed to increased competing vegetation after five years on disked versus scalped sites (however the geographic location of the two treatments also differed).

Hot surface fires can be used to reduce duff and expose mineral soil, however research shows that seeding of jack pine should be delayed by a year after the fire to allow leaching of ash (Kemball et al. 2006). Similarly, increased establishment from seed has been shown to be directly related to decreasing duff thickness (Mallik and Roberts 1994), such as would occur with a fire. However, Ahlgren (1976) also reports that red pine seed germination is inhibited by high ash concentrations and high surface temperatures, such as occur on fire-blackened soil. He suggests that optimal germination conditions occur several years after a burn when ash content is reduced and presumably surface temperatures are less severe.

Because establishment from seed is dependent on the factors outlined above, as well as other factors not discussed (e.g., seed herbivory), attention should be given to seeding at high densities. Manager's guides for red and jack pine recommend seeding at 15,000 - 20,000 repellent coated seeds/acre (Benzie 1977; Gilmore and Palik 2006). However, Benzie and Alm (1977) suggest that seeding red pine at a minimum of 39,000 seeds/acre (3/4 pound) is needed to establish 1,000 seedlings/acre at year 6. Another study found generally higher seedling stocking after two years at sowing rates of 0.5 - 2 pounds/acre compared to 0.25 pounds/acre (Stoeckeler and Sump 1940).

Summary of Direct Seeding Recommendations

Several recommendations for direct seeding emerge from the above research:

1. Seed pines at high densities, perhaps twice the generally recommended rate.
2. Deliberately scarify seeding sites; do not necessarily rely on logging only to adequately prepare the seedbed.
3. Delay seeding for 1 to 2 years after a fire to allow ash content to decline
4. Consider moisture conditions of the site; seed in anticipated better moisture years; deep scarify to improve moisture conditions.

Controlling Competition

The Landscape Committee asked the following questions that are related to competition control as it effects pine establishment.

- *How much competition must be eliminated in order to successfully establish seedlings?*
- *Is fall planting more conducive to establishing a stand?*
- *Do we need to do more maintenance to a stand after planting?*

Control of competing herbaceous and woody vegetation is important for increasing the probability of successfully establishing pine seedlings. While establishing pines from seed requires fairly intense competition control and seedbed preparation, establishing pines from planting is not as exacting. For example, a study by Alm et al. (1978) found that 30-week-old containerized jack pine seedlings had 83% survival after four years when planted into full-tree logged sites having no additional site preparation treatment. Twenty-week-old containerized seedlings had 75% survival after four years.

In a similar study, Benzie and Alm (1977) found that 6th year survival of red pine seedlings planted into a full-tree, summer logged site averaged about 60% for 3-0 seedlings, 76% for one-year-old tubelings, 67% for 16-week-old tubelings, and 41% for 10-week-old tubelings. Again, this method seems a sufficient site preparation to control competing vegetation to achieve good early survival, at least for older and larger planting stock.

The implications of not controlling herbaceous competition in any way during the early post-planting phase is illustrated by the results of a study by Caldwell et al. (1995) in central Minnesota. Red pine seedlings (3-0) planted into undisturbed grass cover had 54% smaller root collar diameters after two years, compared to seedlings planted into sites prepared by spring hand weeding and glyphosate application, followed by continuous hand weeding over the course of the first growing season.

While early survival of planted seedlings may be adequate with even moderate intensity site preparation (e.g., full-tree, summer logging), longer-term survival and growth requires additional follow-up competition control. For instance, a study of planted red pine (3-0) growth in Wisconsin showed a clear relationship between 5th year seedling size and amount of woody shrub competition (Johnson et al. 1998). Seedlings experiencing low levels of shrub and oak sprout competition during the first five years of growth were 50% larger (6.1 ft) than those experiencing moderate levels of competition (4.3 ft), and nearly 100% larger than those experiencing high levels of competition (3.6 ft). Competition levels, defined as amount of brush cover with a 4.5 ft radius circle around the seedlings, ranged from 16.8% (low), to 50% (moderate), to high (68.0%). The importance of releasing pines at around five years of age is suggested by these results. Volume and cover of herbaceous competition (mostly sedges) explained little of the size differences.

Not surprisingly, planting season does seem to be an important influence on planted pine survival. A study by Alm and Schantz-Hansen (1970) in north eastern Minnesota found significantly higher second growing season survival for 42 day old tubelings of jack pine (77%) and red pine (70%) when planted around June 1st, July 1st, and August 1st; compared to 34% survival for jack pine and 21% for red pine when planted on September 1st or 25th. The August 1st plantings had somewhat lower 2nd year survival compared to June and July dates, but was still significantly above the two September dates. Late planted jack pines were less than half the height of the June and July planted seedlings, while August planted seedlings were intermediate in height after two years. September planted red pines were only marginally shorter than June or July planted seedlings and were similar in height to August planted seedlings.

SUMMARY

Successful establishment of pines in northern Minnesota is an issue of continued and growing concern. Some of the causes of failure are generally appreciated by managers (e.g., shoot blights of red and jack pines) and solutions are well established (e.g., planting disease free stock). Some recognized causes are simply beyond the control of managers (e.g., successive drought years); but managers still must be cognizant of the fact that regeneration failures will be high during such conditions.

It is apparent from both the MFRC North Central Landscape Committee questions and from the results of the managers survey, that the two primary causes for pine regeneration failures are believed to be excessive browsing by white-tailed deer and intense competition from woody shrubs and ground vegetation during critical establishment phases. The latter constraint, excessive competition, is probably manageable given the necessary resources to implement site preparation and follow-up competition control. The former constraint, excessive browsing, is much less tractable of a problem.

Although high deer population densities alone are the not sole factor in determining the probability of browse mortality, they certainly are the underlying factor. If excessive deer numbers are not reduced, the problem of widespread pine regeneration failures becomes increasingly difficult to remedy. Although there are solutions for minimizing regeneration failures in the face of high browse pressure, these approaches are costly (e.g., area and individual tree fencing) or variable in the effectiveness (e.g., bud capping, chemical treatments).

Silvicultural solutions are perhaps the most cost effective, but are the least studied and verified.Nonetheless, we suggest they are worthy of greater consideration. Foremost of these include greater use of natural regeneration and direct seeding, since regeneration established from seed appears to be measurably less attractive to browsers. Also, consider targeted competition control, as opposed to area-wide site preparation and follow-up control, to test the idea that seedlings can better escape browsing by “hiding” within a matrix of vegetation. Consider planting large stock. Such seedlings may still be browsed, but are more likely to survive and grow out of browse sensitive heights sooner than small stock. Finally, consider planting and seeding at high densities in an attempt to saturate browsers. The magnitude of the deer browse problem suggests that one approach alone is likely to be variable in effectiveness, but that use of some or all of these measures in combination, perhaps along with bud capping or chemical treatment, may increase the probability of successful pine establishment.

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APPENDIX: NORTH CENTRAL LANDSCAPE COMMITTEE QUESTIONS

Committee Member 1

Deer Browse

- Is deer browsing of seedlings a product of a high deer population?
- What causes deer to seek out seedlings when the deer population is high?
- At what population level will deer browsing of seedlings become a non-factor in plantation establishment?
- Why do deer browse on pine seedlings when they have a relatively low nutritional value compared to other available food sources?
- Can we stop the feeding of deer, which creates artificial carry capacities?
- How do we protect our seedlings?
- Repellants that work?
- Repellants that do not work?
- What kind of structures can we put on them to prevent browse that are cost effective?

Silviculture

- In the NC Landscape, why has direct seeding in clearcuts not been effective?
- Is planting seedlings in rows, especially in trenched sites, adding to the problem?
- Are larger sites better because they have less edge effect per acre?
- What are some alternate silvicultural methods to explore?
- How much competition must be eliminated in order to successfully establish seedlings?
- Is fall planting more conducive to establishing a stand?
- Do we need to do more maintenance to a stand after planting?

Committee Member 2

- What is the level of deer population at which lethal browsing ceases to be a problem in the X area on Y species (based on the way Minnesota measures pre-fawn deer populations)?
- Is there a relationship between the Winter Severity Index (WSI) and browse severity the following growing season (i.e., Is there a reliable relationship)?
- What % of browsing is due to deer? Other species?
- How effective is Plant Skyd, bud capping, large patches, etc. at reducing lethal browsing? Is it cost effective?
- What constitutes lethal browsing or browsing that makes it impossible for a crop tree to develop?
- To what extent is browsing a contributing factor in planting failure? Are the right things being measured and to the appropriate extent?
- To what extent do managers feel that the potential for deer damage is affecting their species selection when designing regeneration projects?
- What is the measurable difference in deer browse damage between nursery stock and natural regeneration? Is there any difference between nurseries or ages of stock? Can fertilization rates be modified to reduce attractiveness?
- What is an acceptable degree of browsing that still allows foresters to get plantings established?

- What is the geographical distribution of browsing at a level that restricts species choice?
- What is the impact of browsing on species other than commercial tree species?
- Are there examples of localized population manipulation that have proven successful?
- More no doubt!

Committee Member 3

- Economic questions have to be addressed. What are the costs of establishing an acre of land in pine versus letting it be established in aspen? (*Low priority)*
- How can deer browse be managed? *(High priority)*
- Selecting the right species to the site while maintaining a return. *(Low priority)*
- What management techniques can be implemented to improve the success rate of acres that are planted to pine to ensure future pine on the landscape? *(High priority)*
- What other management techniques can be used to establish pine other than planting; and is this a viable option given that most of the seed sources such as white pine have already vanished? *(High priority)*

Committee Member 4

- We talked at the last meeting about deer density not always being directly correlated with deer browse damage. So what is the relationship between deer density and degree of browse damage in jack and red pine plantations? This question might be answered by the following two questions.
- What are the common factors to jack and red pine plantation failures across the N.C. Landscape?
- What are the common factors to jack and red pine plantation successes across the N.C. Landscape?

Committee Member 5

- What is the minimum deer herd population levels that would be considered sustainable for wildlife purposes, as well as for forest management purposes? *(Moderate priority)*
- What is the effectiveness, and cost effectiveness of various protection measures (i.e. bud caps, repellants, fences) based on various deer herd populations? *(High priority)*

Committee Member 6

- How can we reduce the amount of young forest, and the fragmentation and edge that occurs due to current forest management practices so we have less habitat for white-tailed deer that are hindering pine regeneration.

Committee Member 7

- Deer browse.
- Site selection criteria.
- Exotic weed control.