Proceedings of the Red Pine

SAF Region V Technical Conference

Editors
Daniel W. Gilmore and
Louise S. Yount

March 26-27, 2002
Cloquet Forestry Center
Cloquet, MN

Staff Paper Series no. 157

July 30, 2002

Department of Forest Resources
College of Natural Resources
University of Minnesota
St. Paul, MN 55108

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

Ph: 612-624-3400
Fax: 612-625-5212
Email: forest.resources@umn.edu

For a pdf version of this publication, use the following link:
http://www.cnr.umn.edu/FR/publications/staffpapers/

Proceedings of the Red Pine

SAF Region V Technical Conference

Editors
Daniel W. Gilmore and
Louise S. Yount

March 26-27, 2002
Cloquet Forestry Center
Cloquet, MN

Staff Paper Series no. 157

July 30, 2002

Department of Forest Resources
College of Natural Resources
University of Minnesota
St. Paul, MN 55108

UNIVERSITY
OF MINNESOTA

The authors are, respectively, Assistant Professor, Department of Forest Resources, North Central Research and Outreach Center, Grand Rapids, MN 55744; and Asst. Coordinator of Continuing Education, College of Natural Resources, Cloquet Forest Center, Cloquet, MN 55720. Research was supported by the Department of Forest Resources and the Center for Continuing Education, College of Natural Resources, University of Minnesota; the USDA Forest Service; and the Sustainable Forests Education Cooperative.

Preface

Red pine is a tree species important to the ecology, culture, and economy of the Lake States Region and northeastern North America. Several conferences focusing on red pine management have been held during the last 20 years including the SAF Region V Technical Conference held in Marquette, Michigan, in 1984[1] and the Michigan SAF Fall Workshop on Red Pine Management held in Manistique, Michigan, in 1997. The purpose of the Red Pine SAF Region V Technical Conference held at the University of Minnesota, Cloquet Forestry Center on March 26-27, 2002 was to present the "state of the art" in red pine management and research to resource managers and field practitioners and to facilitate discussion between researchers and forest managers.

This web-available proceedings includes papers and abstracts provided by those invited to present their perspective on red pine management at the conference. We also have included a paper describing the history of the oldest research plantation in Minnesota established by Herman H. Chapman at the University of Minnesota, North Central Research & Outreach Center in 1900 written by Tim O'Brien and Keith Matson. We gratefully acknowledge the work of the conference organizing committee, listed below, for their hard work in developing the program and inviting speakers.

Daniel W. Gilmore
Assistant Professor of Silviculture
Department of Forest Resources
University of Minnesota

Louise S. Yount
Coordinator, Sustainable Forestry
Education Cooperative
University of Minnesota

Conference Organizing Committee

Bill Cook - Michigan SAF
Gene Francisco - Wisconsin SAF
Roger Misiak - Michigan SAF
John Thompson - Minnesota SAF
Bill Rockwell - Region V SAF
Tom Crow – USDA Forest Service
Andy David – UMN, Dept. For. Res.
Alan Ek - UMN, Dept. For. Res.
Dan Gilmore - UMN, Dept. For. Res.
Mike Reichenbach – MN Extension Service
Louse Yount - UMN Center for Continuing Education
John Johnson - MeadWestvaco
Gary Wyckoff - MeadWestvaco
Tom Murn - Potlatch
Jim Marshall - UPM Kymmene
Jack Rajala - Rajala Companies and Minnesota Forest Resources Partnership
Brian Smith - Potlatch
Mike Young - International Paper
Tim Tollefson - Stora Enso
Rick Klevorn - MN DNR
Trent Marty - WI DNR
Garrett Ous - Minnesota Association of County Land Commissioners and Itasca County

---

[1] Marty, R., ed. 1985. *Managing red pine*. Society of American Foresters, Bethesda. SAF Publication 85-02.

Table of Contents

Page

Table of Contents (continued)

Page

Introduction to the Red Pine SAF Region V Technical Conference, March 26-27, 2002

Thomas R. Crow, USDA Forest Service, North Central Research Station,
Grand Rapids, MN 55744 tcrow@fs.fed.us[1]

Research on managing red pine has been ongoing for some time and management guides that incorporate information resulting from this research such as Buckman's (1962) *Growth and Yield of Red Pine in Minnesota* and Benzie's (1977) *Manager's Handbook for Red Pine* have been widely applied. Despite this extensive knowledge base, critical information needs remain. Additional information about growth and yield, especially under managed conditions, is needed. Alternatives to single species and even-aged management are needed in which red pine is a component in forests consisting of multiple species and multiple cohorts. Red pine management needs to be considered within the broader spatial context of the landscape, and even at regional and global scales. And finally, much remains to be learned about the natural regeneration of red pine.

The need for new information results from the changing social and economic conditions in which we manage the forest. For example, the global demand for wood, especially softwood, continues to increase at a rate that exceeds population growth. There is increased global competition among forest industries, resulting in increased emphasis on cost efficiency in order to remain competitive in the marketplace. Loggers find it increasingly difficult to stay in business. Social and economic forces from outside of the region greatly affect the health of the forest economy within the Lake States (Hagenstein 1997). Without question, there are increased demands for a wider spectrum of outputs, benefits, and values from the forest in the Lake States and so forest managers need to be more strategic about where they are going to grow wood on the landscape and managers will need to do it in a more integrated way so that multiple benefits are achieved. Including a more explicit spatial element in the business of forestry will help address questions regarding where, when, and how wood should be grown (Crow and Gustafson 1997). A spatial perspective will help to deal also with landscape issues such as forest fragmentation and ownership parcelization. Owners of smallholdings, for example, face significant challenges related to the economies of scale (Kingsley 1997).

These and other "new realities" suggested that it is timely to review what we know about managing our Lake States forest. Red pine is an important part of this regional forest. Today red pine occupies nearly 2 million acres, about 4% of the commercial forest land in Wisconsin, Michigan, and Minnesota. Much of the red pine occurs in plantations. For

---

[1]Crow, T. R. 2002. Introduction. In *Proceedings of the Red Pine SAF Region V Technical Conference*, eds., Gilmore, D. W., and L. S. Yount, 1-2. Staff Paper no. 157. St. Paul, MN: University of Minnesota, College of Natural Resources, Department of Forest Resources.

example, nearly 80% of the red pine in Wisconsin has been planted (Roussopoulos and Leatherberry 1992). Compared to almost all other species common to the Lake States forest, red pine has an advantage in growth rate. Growing red pine offers an opportunity to increase the productivity of the regional forest.

Our goal at this Society of American Foresters Region Conference was to offer a high quality, comprehensive, technical conference that covers both basic knowledge and new findings about the management of red pine in the Lake States. Speakers at the Conference presented the current status of the resource, gave us a sense of where we have been and where we are likely to go with red pine management, revisited the subjects of growth and yield as well as regeneration, talked about ecological classification and its application in red pine management, expanded our vision about the possibilities of managing red pine in stands of mixed species and multiple cohorts, reviewed important disease and insect problems, and considered utilization, markets, and price trends. The Conference was organized as a first step toward revising the management guide for red pine. The North Central Research Station published the current guide in 1977. The revision will be a collaborative effort among researchers from several organizations. The guide will be a "how to" document; the technical information that forms the basis for the revised management guide can be found, in large part, among the pages of this proceeding.

Literature Cited

Benzie, J. W. 1977. Manager's handbook for red pine in the north central states. USDA Forest Service, North Central Forest Experiment Station, General Technical Report NC-33. 22 p.

Buckman, R. E. 1962. Growth and yield of red pine in Minnesota. USDA Tech. Bull. 1272. 50 p.

Crow, T. R., and E. J. Gustafson. 1997. Ecosystem management: managing natural resources in time and space. In *Creating a Forestry for the 21st Century, The Science of Ecosystem Management*, eds., Kohm, K. A., and J. F. Franklin, 215-228. Washington, D.C.: Island Press.

Hagenstein, P. R. 1997. Interregional competition and the Lake States forest resources. In *Lake States Regional Forest Resources Assessment: Technical Papers*, eds. Vasievich, J. M., and H. H. Webster, 270-289. Technical Report NC-189. St. Paul, MN: USDA Forest Service, North Central Forest Experiment Station.

Kingsley, N. P. 1997. Resource availability from nonindustrial private forest land in the Lake States. In *Lake States Regional Forest Resources Assessment: Technical Papers*, eds. Vasievich, J. M., and H. H. Webster, 72-76. Technical Report NC-189. St. Paul, MN: USDA Forest Service, North Central Forest Experiment Station.

Roussopoulos, S. M., and E. C. Leatherberry. 1992. Wisconsin's timberland plantations, 1983. Resource Bull. NC-137. St. Paul, MN: USDA Forest Service, North Central Forest Experiment Station, 24 p.

Red Pine in the Northern Lake States

Thomas L. Schmidt, Research Forester, Forest Inventory and Analysis Program,
North Central Research Station, 1992 Folwell Ave., St. Paul, MN 55108
651-649-5131 Tschmidt@fs.fed.us[1]

ABSTRACT. Red pine is an important tree species for the Northern Lake States. About 4 percent of the total area of timberland is dominated by red pine but most other forest types also have red pine as a component. The red pine forest type in the region has dramatically increased in area since the 1930s. Stand-size class distribution of the red pine forest type has changed over time in the region to where currently; sawtimber-sized stands represent 41 percent of the total red pine forest type acreage. Over time the total area of red pine has remained at about 60 percent privately owned. Stocking levels, total number of trees, growing-stock volume, average annual net growth, and average annual removals have all increased over time in this region. Currently, the region's average annual net growth for red pine is five times as high as its removals.

KEY WORDS. Red pine, area, volume, growth, change

Red pine (*Pinus resinosa*) has historically been one of the most important woody plant species throughout the Northern Lake States. This importance was based on more than just a timber production perspective. Red pine makes important ecological contributions in watershed protection and soil stability, contributes to the region's well-known aesthetics and recreational opportunities, and is an important component of the region's forest lands for wildlife habitat. While it is difficult to determine the extent of red pine prior to European settlement, it is believed that, in conjunction with white pine (*Pinus strobus*), it was one of the dominant vegetative features of the landscape. With European settlement and the ensuing logging of the resource, red pine, white pine, hemlock (*Tsuga canadensis*), and white spruce (*Picea glauca*) were the most heavily harvested conifer species. As a result, by the early 1900s the forested landscape across the Northern Lake States was impacted to the point where it was often referred to as "stumplands." By 1996, only 2 percent of the total forest land resource in this region had average stand ages of more than 120 years and an additional 14 percent had average stand ages of between 80 and 120 years (Schmidt et al. 1996). Of the determined old and potential old forest land, only 2 percent was classified as being in the red pine forest type. Thus, only small remnants of the red pine forests existing prior to the turn of the 20th century still exist today.

[1] Schmidt, T. L. 2002. Highlights–Red pine in the northern Lake States. In *Proceedings of the Red Pine SAF Region V Technical Conference*, eds., Gilmore, D. W., and L. S. Yount, 3-16. Staff Paper no. 157. St. Paul, MN: University of Minnesota, College of Natural Resources, Department of Forest Resources.

Despite this adverse outlook for forest lands in the early 1900s, like a Phoenix rising from the ashes, forest lands across the Northern Lake States at the turn of 21st century have returned to dominate the landscape. The current forest land resource is different from what was first encountered by European settlers but nevertheless is of utmost value and importance. Documenting the resurgence of red pine in the context of the resurgence of the overall forest land resource of the Northern Lake States will improve our understanding of the resource and assist with development of management strategies.

Methods

Data presented are from the USDA Forest Service, Forest Inventory and Analysis' (FIA) Database (Miles et al. 2001), and are based on FIA statewide forest inventories for each state. The dates of the FIA inventories are Michigan 1935, 1955, 1966, 1980, and 1993; Wisconsin 1936, 1956, 1968, 1983, and 1996; and Minnesota 1936, 1953, 1962, 1977, and 1990. Data presented generally pertain only to timberland, however, more than 95 percent of the forest land in the Northern Lakes States region is classified as timberland (Powell et al. 1993). Timberland is forest land capable of producing more than 20 cubic feet per acre per year of industrial wood crops under natural conditions and not withdrawn from timber utilization. There are other classifications of land with trees, including reserved forest land, narrow planted and natural wooded strips, and pasture land with trees that do not meet the timberland definition. These nontimberlands make important contributions to the many forest-related resources and their use and do contain red pine. Until recently, FIA did not install field plots on these other forest lands and, as a result, data are very limited for forest land classifications other than timberlands.

Red pine forest type classification is based on forest lands where red pine trees comprise a plurality of the total stocking. Common associates in the red pine forest type are white pine, jack pine (*Pinus banksiana*), aspen (*Populus* spp.), birch (*Betula* spp.), and maple (*Acer* spp.). For red pine stand-size class determinations, sawtimber-sized stands are stands with half or more of the total live tree stocking in trees that are at least 9.0 inches d.b.h. Stand age is based on the average age of the dominant and codominant trees in the stand. Volume is the net volume of trees 5.0 inches d.b.h. and over, from 1 foot above the ground (stump) to a minimum 4-inch top diameter outside bark or to the point where the central stem breaks into limbs. Growing-stock volume is used in this study, which represents the volume in growing-stock trees (trees that meet specified standards of size, quality, and merchantability) more than 5.0 inches d.b.h.

FIA implements a systematic grid for its estimates. From the grid, plots are selected for determinations of land use through remote sensing. A subset of these plots is selected for field measurement where plot level and individual tree measurements are made. All data presented originated as field measures through the FIA program. Additional information regarding the red pine and overall forest land resource of the Northern Lake States can be obtained via the FIA Database at: (http://www.ncrs.fs.fed.us/4801/FIADB/index.htm).

Results

Area

Within the Northern Lake States, there are currently 122 million acres of land, 43 percent of which is classified as forest land. Of the 52 million acres of forest land, 49 million acres are timberland, 1.9 million acres are reserved forest land, and almost 1 million acres are classified as other forest land (land that does not meet minimum productivity standards). The red pine forest type represents 1.9 million acres of timberland and 104 thousand acres of reserved forest land. The area of forest land dominated by red pine represents about 4 percent of the total forest resource of the Northern Lake States region.

In addition to those timberlands that are dominated by red pine (and thus classified as being in the red pine forest type), some red pine can be found in almost all other forest types. Red pine plays a significant role in some forest types, while in others it is a minor component. In the 1993 inventory of Michigan, red pine represented more than 11 percent of the total volume in the jack pine forest type and 9 percent of the volume in the white pine forest type, but only 0.5 percent of the maple-beech-birch (*Acer-Fagus-Betula*) forest type. Ensuing discussions related to the area of red pine focus primarily on the red pine forest type but this species has a far greater impact than that portrayed simply by where it is the dominant species. Red pine makes significant contributions to economic, social, and biological diversity as well as the long-term sustainability of these other forest types. Thus, while the red pine forest type accounts for only 4 percent of the total area of forest land in the Northern Lake States, its overall impact is greater.

The red pine forest type in the Northern Lake States has dramatically increased in area since the 1930s (Fig. 1). In the 1930s, Minnesota had the most area of timberland classified as red pine. However, since the 1950s Michigan has led the region in terms of total area of red pine and currently represents almost half of all red pine dominated forests. Increases in area of red pine have occurred through both natural and artificial (primarily planting seedlings) regeneration. While the majority of the increases experienced from the 1930s through the 1960s were due to establishment efforts (both natural and artificial), the majority of the increases in the 1980s and 1990s were due to reclassification from other forest types to the red pine forest type.

For example, in Michigan between 1980 and 1993, the area classified as red pine timberland increased by 309 thousand acres. Of this increase, 76 percent was due to reclassification of existing timberland from other forest types to the red pine forest type and 24 percent was from lands that previously were not timberlands. Of the 76 percent that was reclassified from other forest types to red pine, 25 percent was from jack pine stands, 19 percent was from maple-beech-birch, 17 percent was from oak-hickory (*Quercus-Carya*), and the remaining 15 percent was from other forest types to red pine.

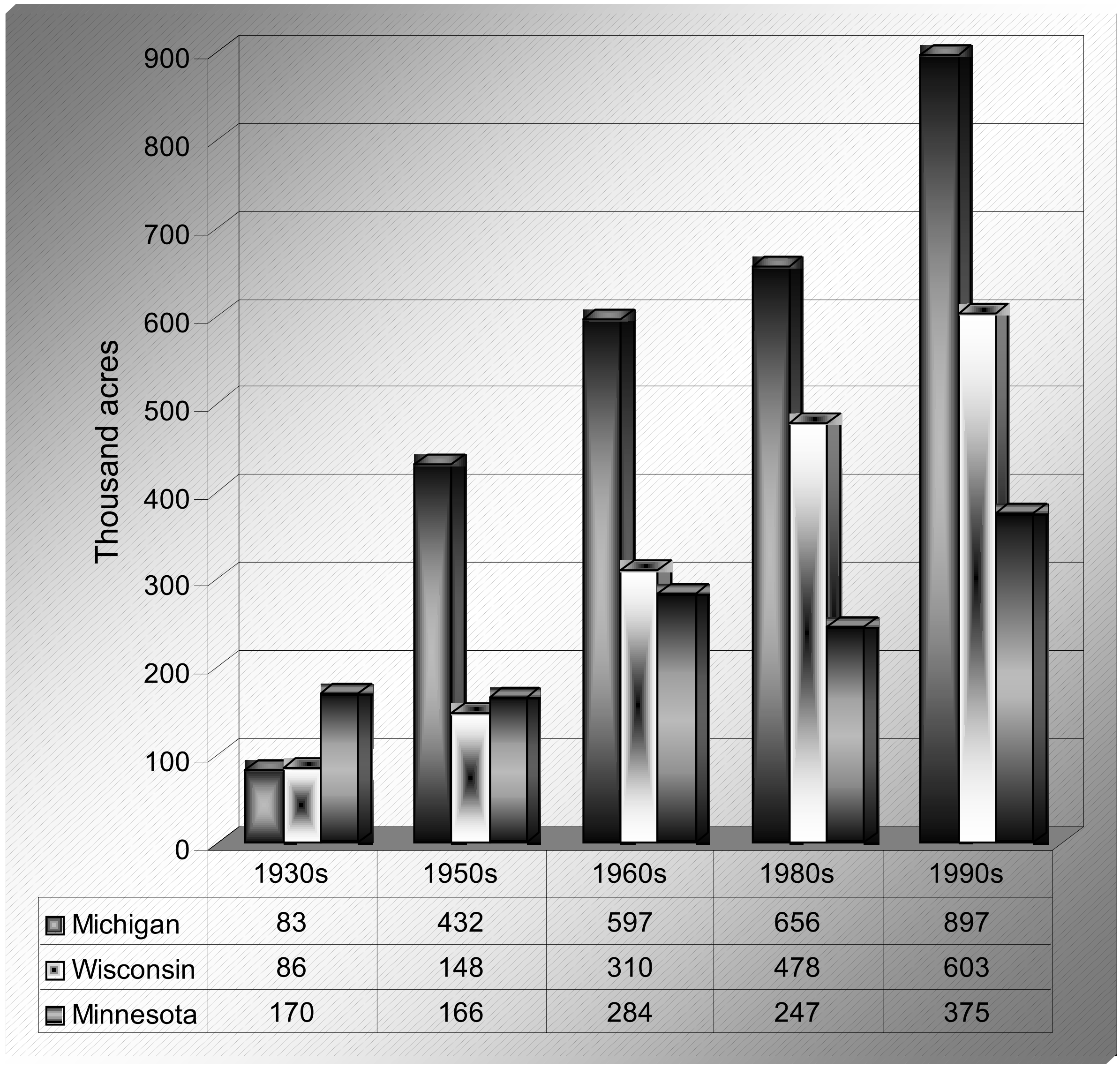
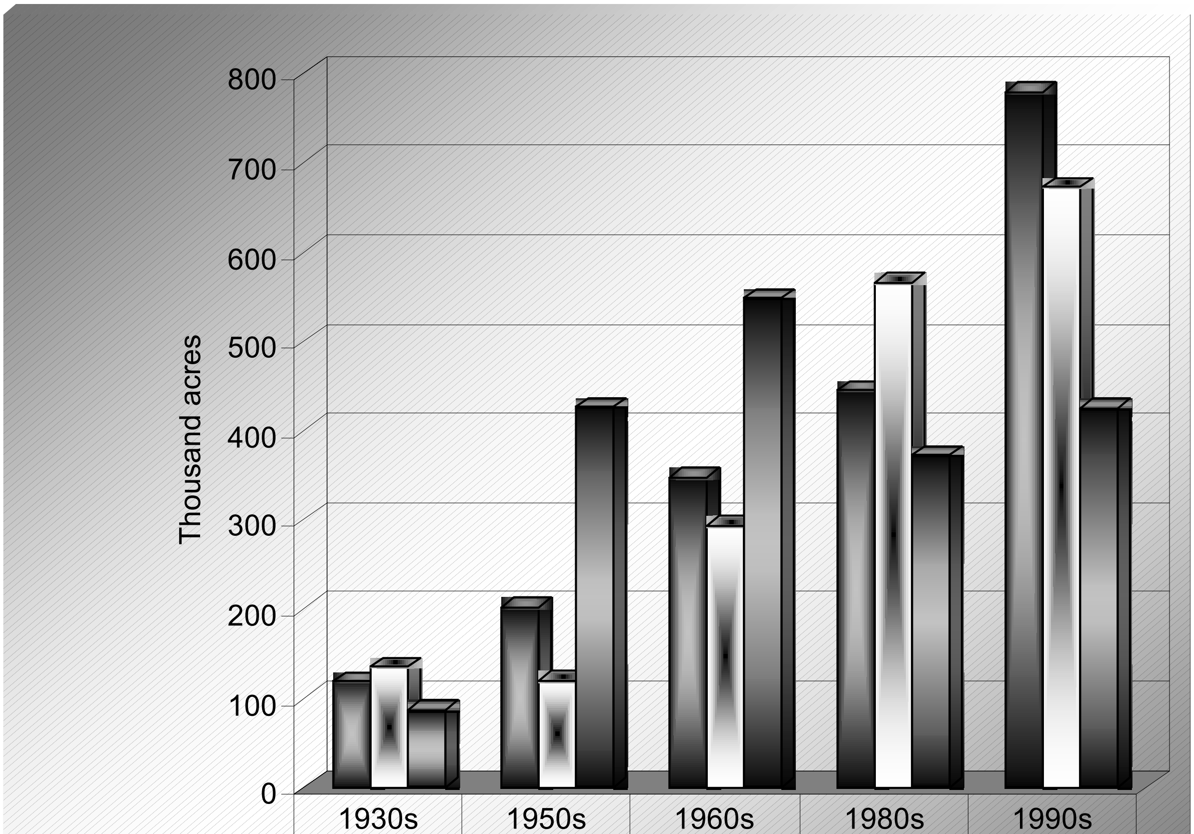


Figure 1. Area of red pine forest type in the Northern Lake States.

Stand-Size

The stand-size class distribution of the red pine forest type has changed in the Northern Lake States. In the 1930s, sapling-seedling sized stands represented about one-fourth of all red pine timberlands (Fig. 2). By the 1950s, sapling-seedlings accounted for more than 57 percent of all red pine timberlands. From the peak in the 1950s, the area of red pine in sapling-seedling sized stands has progressively declined (1960s-46 percent, 1980s-27 percent, and 1990s-23 percent). While the sapling-seedling sized stands have declined in total area, a corresponding increase has occurred in the area of sawtimber-sized red pine stands. Currently, across the Northern Lake States, sawtimber-sized stands represent 41 percent, poletimber-sized stands 36 percent, and sapling-seedling sized stands 23 percent of the total red pine forest type acreage. On a state basis, both Minnesota and Michigan follow similar trends but Wisconsin currently has a lower level of sawtimber-sized red pine stands.

This difference in red pine by stand-size class is similar for most other forest types in these three states. Across almost all forest types, Wisconsin has lower levels of sawtimber-sized stands than the other states.



	1930s	1950s	1960s	1980s	1990s
Sawtimber	118	201	347	444	779
Poletimber	135	119	294	565	673
Seedling-Sapling	86	426	548	372	424

Figure 2. Area of red pine forest type in the Northern Lake States by stand-size class.

Ownership

Ownership of the overall timberland resource in the Northern Lake States has been relatively static over the past 40 years. While there have been changes, most have been minor involving a small percentage of the overall resource. For the total timberland resource across the region, slightly more than 60 percent is privately owned and slightly less than 40 percent is publicly owned. At the same time, the total area of red pine timberland has remained at about 60 percent publicly owned and 40 percent privately owned, reflecting that red pine is predominately a public resource. This has implications in that those producers that are dependent on red pine wood fiber rely more heavily on the public sector for their supply than most other forest product enterprises. There have been changes in ownership within the public sector. Federal ownership of red pine slightly decreased between the 1980s and

1990s, primarily due to successional processes that resulted in a reclassification to a different forest type, typically toward a deciduous type. At the same time, the area of red pine timberland owned by state and local government increased by two-thirds (Fig. 3). The increase in state and local government's area of red pine could be a reflection of their forest management being directed at maintaining red pine with its potentially strong economic returns.

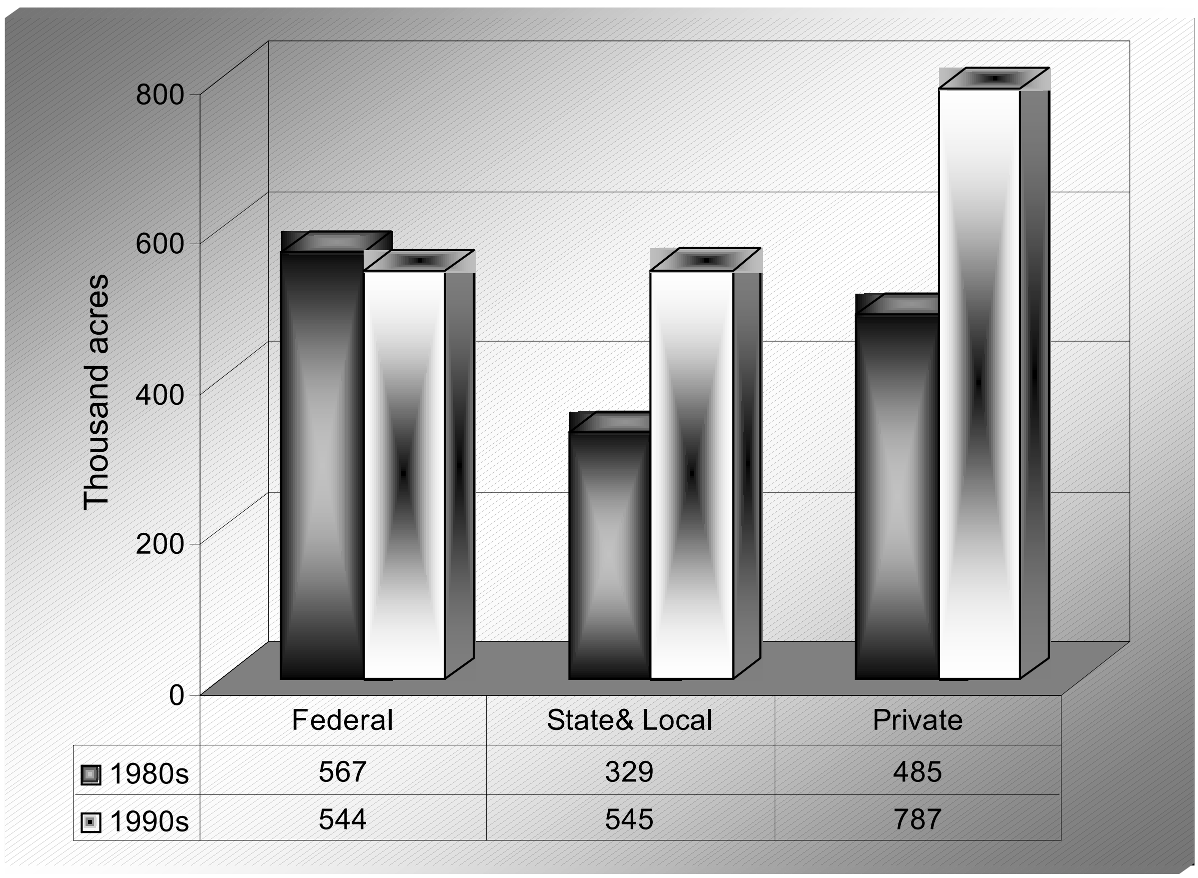


Figure 3. Area of red pine forest type in the Northern Lake States by ownership class.

The area of privately owned red pine timberland increased by more than 60 percent between the 1980s and the 1990s, but with the overall increase in total area of red pine, the percentage in private ownership remained at the same level. In addition to potentially increasing in area due to management, the conversion of other forest types to red pine has occurred. In many stands, both jack and red pine occur on the same site. Without disturbance, and with the increasing age of the stands initially established around the turn of the century, jack pine are phasing out, leaving red pine as the dominant species. This ecological process results in a reclassification of many stands from jack to red pine.

Stocking

Across the Northern Lake States, the level of stocking (how fully occupied the site is by trees) has increased. Data related to stocking by specific forest type is only available for inventories completed since the 1980s. Between the 1980s and the 1990s, the percentage of red pine timberland in the poorly to medium stocking classes decreased from 40 percent to 29 percent (Fig. 4). This decrease was due to an increase in the area of fully stocked timberland. The increase in stocking levels is due to the continuing positive growth-to-removals ratios experienced across the region, which are discussed in detail in the factors of change section.

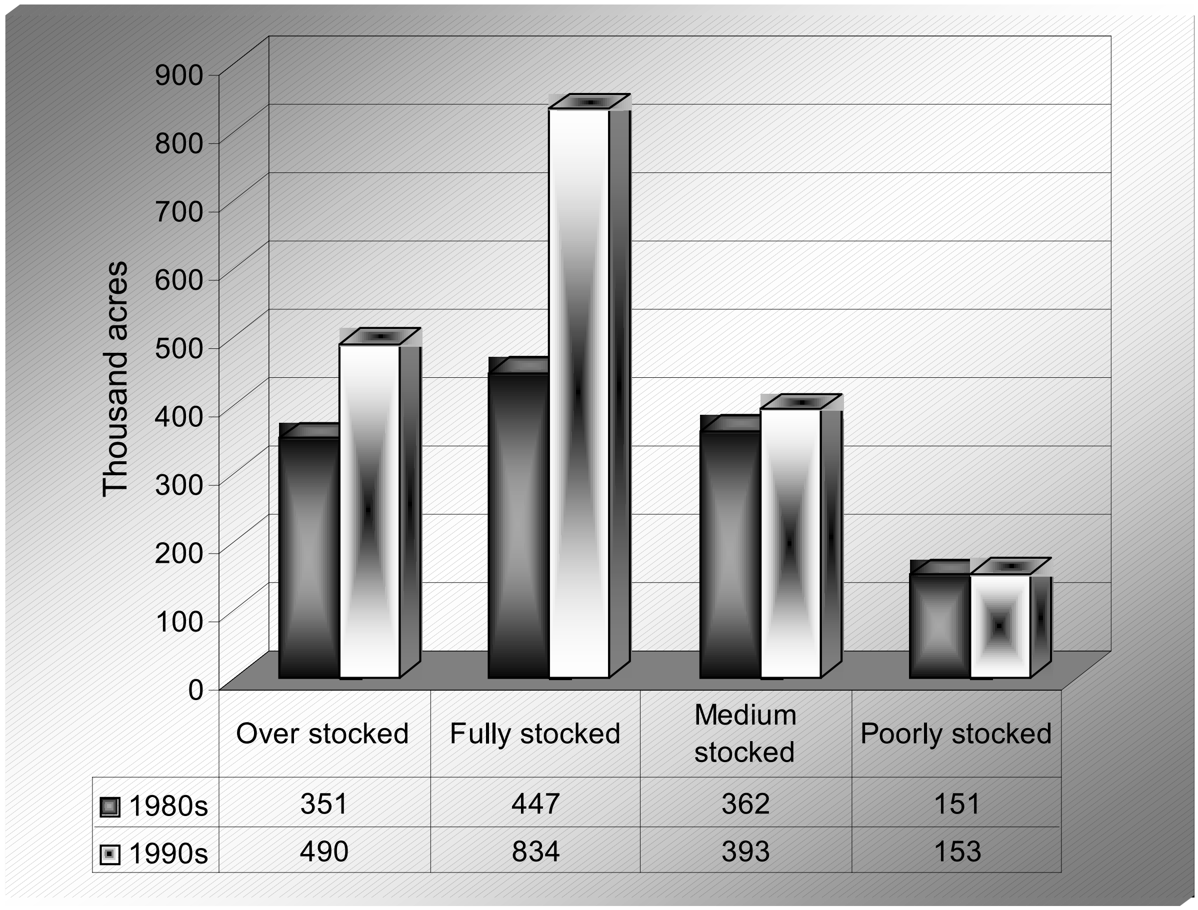


Figure 4. Area of red pine forest type in the Northern Lake States by stocking class.

Number of Trees

Discussions regarding the number of red pine trees relate to all red pine trees regardless of the forest type. As mentioned, red pine can be found in a number of forest types, thus management activities, successional processes, and land-use changes that impact all timberlands have the potential to impact the number of red pine trees. Until the 1990s, the number of red pine trees in the Northern Lake States followed the generally accepted standard distribution of the most trees in the smallest diameter size class and, as diameters increased, the number of trees decreased (Fig. 5). However, in the 1990s, the number of red pine trees in the 0to5 inch diameter class was lower than the number in the 5-to-9 inch diameter class. The 5-to-9 inch diameter class had the most red pine trees in the 1990s, followed by the 0-to-5 inch diameter class, followed by the standard decreasing number of trees as diameter increases. The primary reason for this was the large number of trees in

Michigan in the 5-to-9 inch diameter class but this unusual situation might also imply a concern regarding regeneration of red pine.

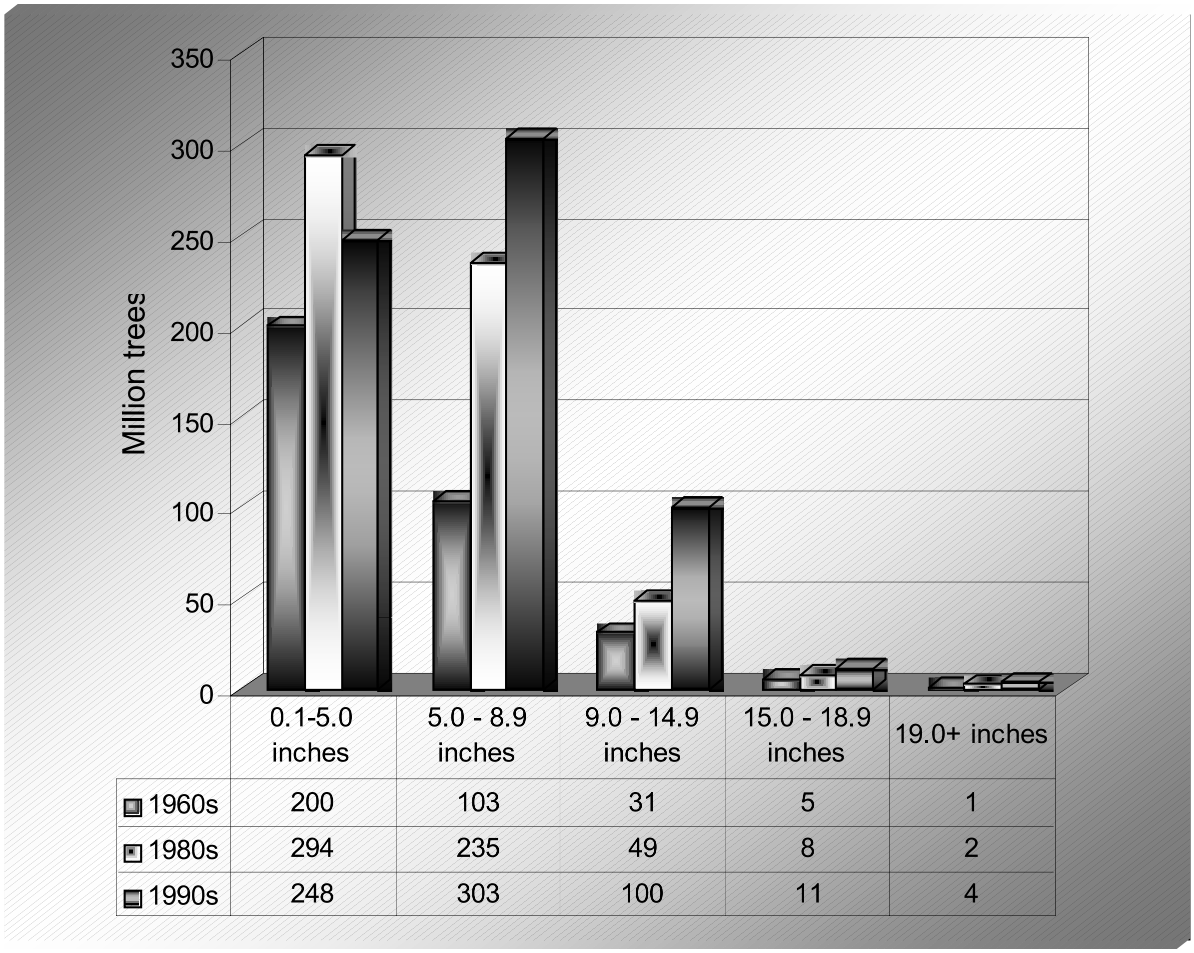
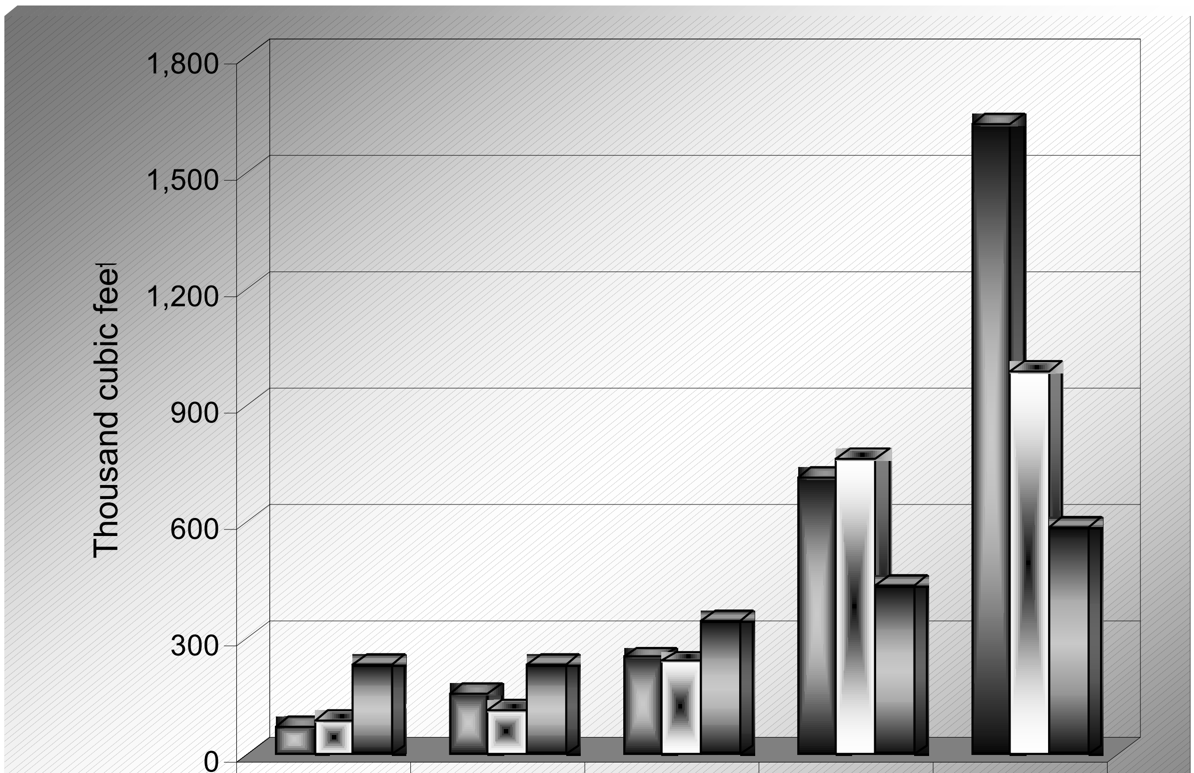


Figure 5. Number of red pine trees in the Northern Lake States by diameter class.

The number of larger diameter red pine trees in the region has been steadily increasing over time. As the timberlands across the region have been maturing, red pine has followed suit. This also matches with the analysis of stand-size class; the area of sawtimber sized red pine stands has been steadily increasing across the Northern Lake States. It is expected that in the absence of disturbance and/or management specifically directed at regeneration, the number of smaller sized red pine trees might decrease across the region with a corresponding increase in larger diameter red pine trees. As these larger trees reach full maturity and increase their susceptibility to environmental stresses, mortality is expected to increase. If this occurs, these larger red pine trees will be replaced and the stand might convert to other forest types.

Growing-Stock Volume

Across the Northern Lake States, total growing-stock volume for all species has steadily increased. Between the 1930s and the 1990s, total growing-stock volume increased by 133 percent. Each inventory period resulted in greater volumes for almost all forest types and species groups. This continual increase occurred in all three states on a regular basis. This same phenomena has occurred with red pine but to a much greater extent. Between the 1930s and the 1990s, total growing-stock volume of red pine increased by more than 700 percent (Fig. 6). Volume of red pine in the Northern Lake States region is currently greatest in the east and decreases as you progress west. Michigan has almost three times as much red pine volume as Minnesota.

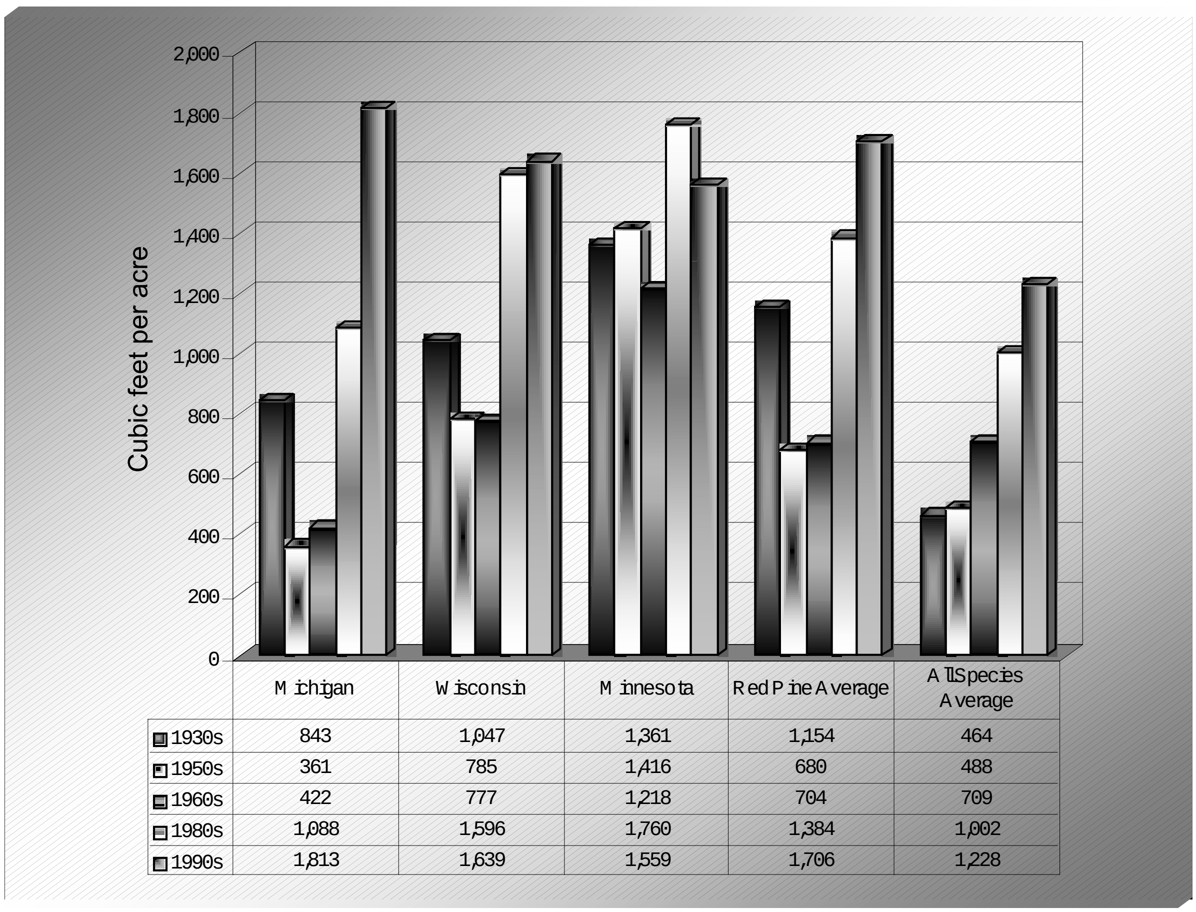


	1930s	1950s	1960s	1980s	1990s
Michigan	70	156	252	714	1,627
Wisconsin	90	116	241	763	988
Minnesota	231	235	346	435	585

Figure 6. Growing-stock volume of red pine in the Northern Lake States.

While red pine occurs across almost all forest types and thus there is red pine volume that is not accounted for by the red pine forest type, there are other species that occur within the red pine forest type. For example in Michigan in 1993, 80 percent of the total red pine volume was in the red pine forest type and about 80 percent of the total volume in the red pine forest type was red pine. Thus, calculations based on average volume per acre seem reasonable (total red pine growing-stock volume by total area in the red pine forest type). Across all inventory periods, red pine volume per acre equaled or exceeded the average for all species. From the 1930s through the 1980s, red pine volume per acre was the lowest in Michigan and greatest in Minnesota. However, by the 1990s Michigan had the greatest level of red pine volume per acre and Minnesota had the lowest among the three Northern Lake States.

In the 1990s, red pine growing-stock volume averaged more than 1,700 cubic feet per acre across the region compared to 680 cubic feet per acre in the 1950s, an increase of 150 percent (Fig. 7). Average growing-stock volume for all species averaged 1,228 cubic feet per acre in the 1990s, exhibiting the heavier stocking associated with this species.



	Michigan	Wisconsin	Minnesota	Red Pine Average	All Species Average
1930s	843	1,047	1,361	1,154	464
1950s	361	785	1,416	680	488
1960s	422	777	1,218	704	709
1980s	1,088	1,596	1,760	1,384	1,002
1990s	1,813	1,639	1,559	1,706	1,228

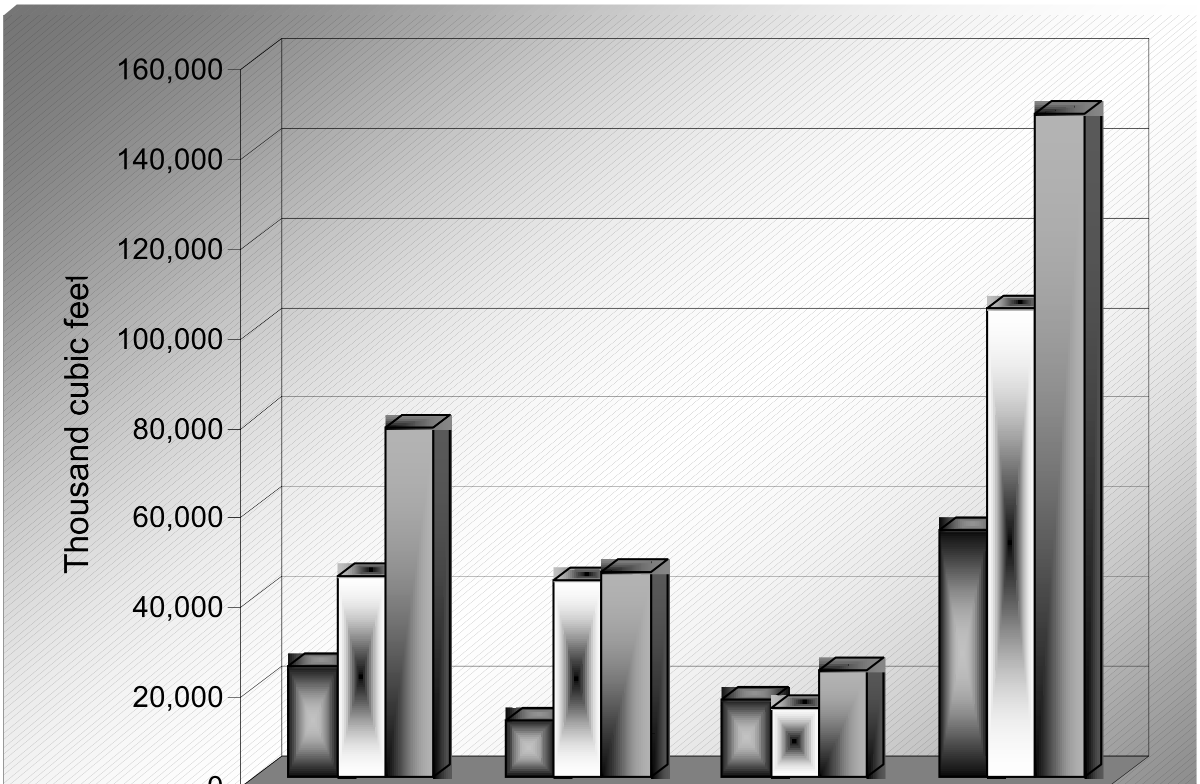
Figure 7. Growing-stock volume per acre of red pine in the Northern Lake States.

Factors of Change

There are three major factors of change with common measurements—average annual growth, mortality, and removals. While there are other factors of change, common measurements have not historically been made, thus the focus on these three factors of change. Most growth measures are reported as average annual net growth, which reflects gross growth minus mortality. In the case of red pine, mortality averages 0.06 percent of total growing-stock volume and 1.3 percent of total gross growth, thus discussions related to growth focus on average annual net growth for growing stock. Removals are totals and include removals due to land-use change, harvesting for all wood fiber products, and logging slash left in the woods. Growth-to-removal ratios compare average annual net growth to average annual removals.

Growth

Average annual net growth for red pine has consistently increased across the region and in each state since the 1960s (Fig. 8). For the region as a whole, between the 1960s and the 1990s, total red pine average annual net growth increased by more than 160 percent. The majority of the growth has occurred in Michigan. Michigan accounted for 45 percent of the total red pine growth in the region in the 1960s, 43 percent in the 1980s, and 52 percent in the 1990s.



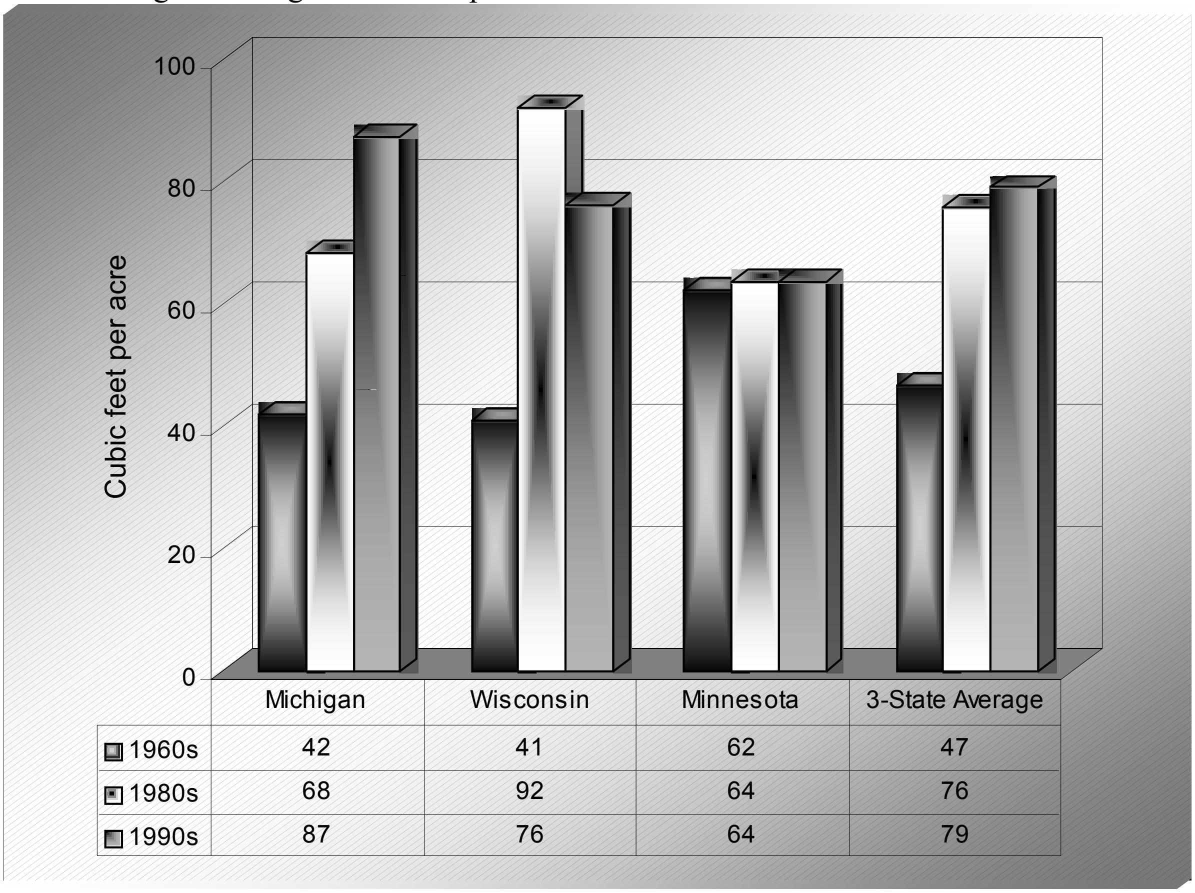
	Michigan	Wisconsin	Minnesota	Total
1960s	25,064	12,628	17,684	55,376
1980s	44,857	43,977	15,684	104,518
1990s	78,310	45,877	23,874	148,061

Figure 8. Average annual net growth of red pine in the Northern Lake States.

On a growth per acre basis, Minnesota has consistently averaged about 60 cubic feet of growth per acre per year (Fig. 9). Michigan has steadily increased to where it currently averages almost 90 cubic feet per acre per year. Across the three states, red pine averages almost 80 cubic feet per acre per year of net growth.

Mortality

Red pine historically has one of the lowest rates of mortality of all woody species in the Northern Lake States region. While mortality has been increasing, from 352 thousand cubic feet per year for the region in the 1980s to 1,971 thousand cubic feet per year in the 1990s, it still only represents 0.06 percent of total volume. As a comparison, mortality of all species across the region averaged about 1.0 percent of total volume in the 1990s.



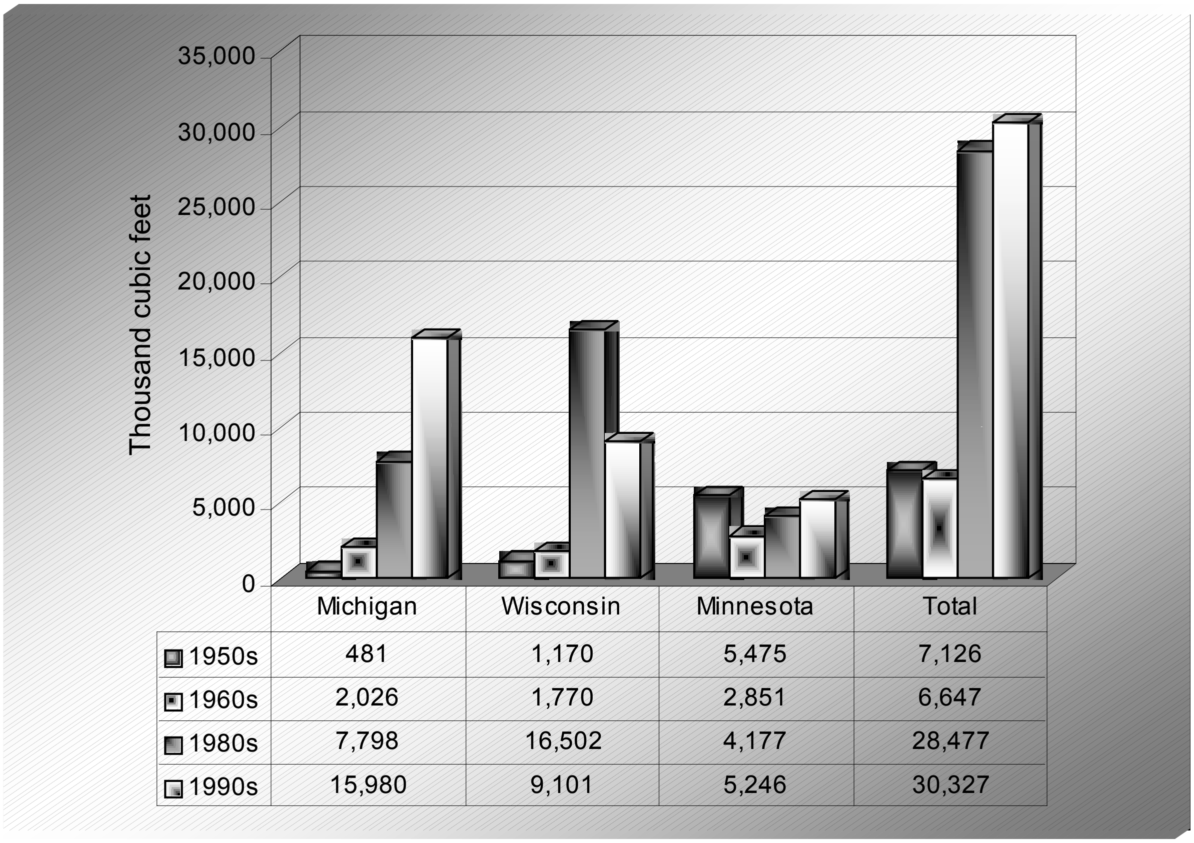
	Michigan	Wisconsin	Minnesota	3-State Average
1960s	42	41	62	47
1980s	68	92	64	76
1990s	87	76	64	79

Figure 9. Average annual net growth per acre of red pine in the Northern Lake States.

Of the known causes of mortality, weather and fire were the leading causes followed to a lesser extent by insects and diseases. Currently, mortality of red pine is greatest in Wisconsin (about a million cubic feet per year) but it is at a low level and should not be of major concern. If the red pine resource continues to age and is not replaced by younger, more vigorous trees, it is expected that mortality rates will continue to increase and might become of concern in the future.

Removals

Average annual removals of red pine dramatically increased from the 1950s to the 1980s across the region (Fig. 10). From the 1980s to the 1990s, removals increased by 100 percent in Michigan, increased by 25 percent in Minnesota, and declined by 45 percent in Wisconsin. Recent differences between states partially reflect differences in their forest products industries and partially reflect resource availability. Currently, the Northern Lake States region averages slightly more than 30 million cubic feet of red pine removed annually. Interestingly, red pine removals currently represent 4 percent of all removals, matching the percentage for total area of timberland dominated by red pine.



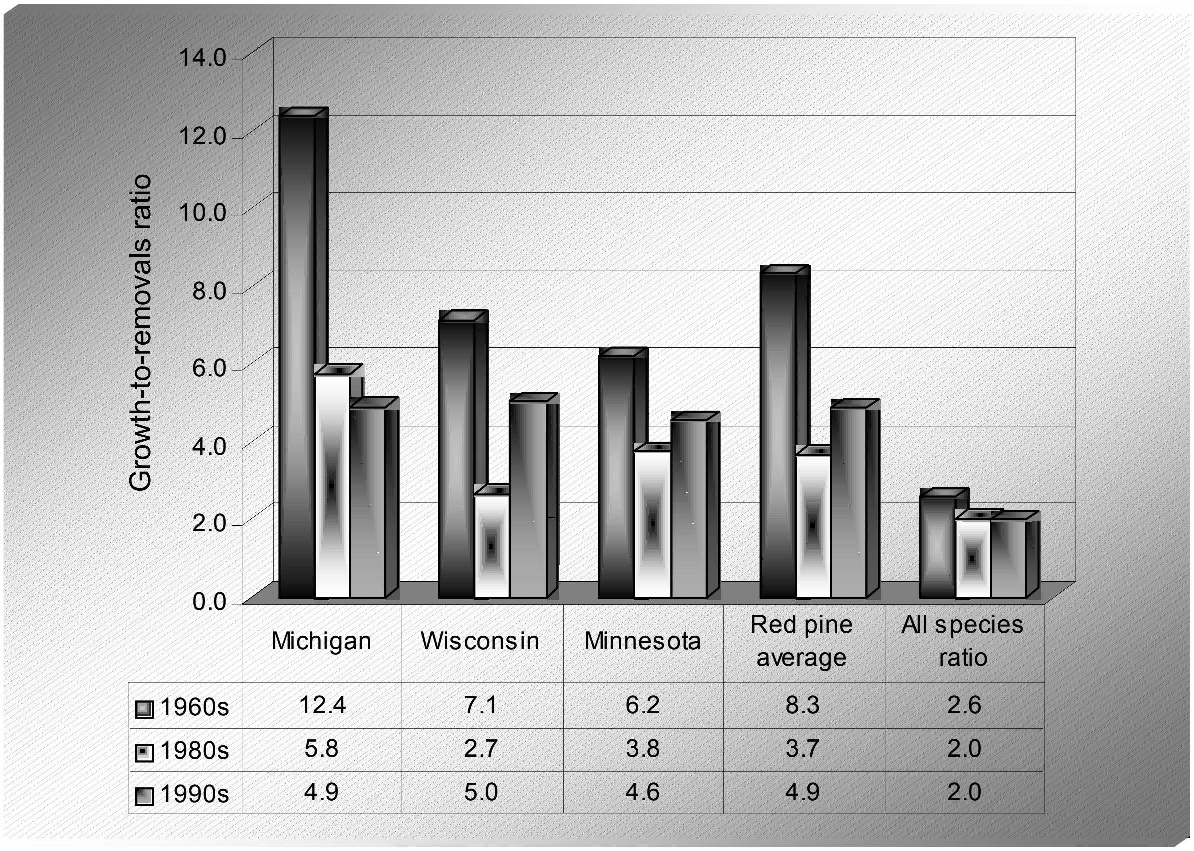
	Michigan	Wisconsin	Minnesota	Total
1950s	481	1,170	5,475	7,126
1960s	2,026	1,770	2,851	6,647
1980s	7,798	16,502	4,177	28,477
1990s	15,980	9,101	5,246	30,327

Figure 10. Average annual removals of red pine in the Northern Lake States.

Analyzing growth-to-removals ratios for red pine reveal that between the 1960s and the 1980s the ratio decreased, exhibiting that removals were increasing in relation to growth (Fig.11). However, between the 1980s and the 1990s the region's growth-to-removal ratio has been increasing. Currently, the Northern Lake States have a growth-to-removals ratio of almost 5-to-1, implying that five times as much growth is occurring as is being removed. The region averages a growth-to-removals ratio of about 2-to-1 when all species are considered.

Discussion

Red pine is a vital component of the timberland resources in the Northern Lake States region and with its current condition is expected to continue its critical role. One of the areas of concern relates to the decreasing levels of regeneration compared to other diameter classes. This situation is similar for all timberlands in the region as they continue to mature and move toward a more sawtimber-size dominated status. Current and future policy and management decisions regarding the overall forest resource and red pine in particular will have to address this situation and the resource will reflect their outcome. While the current future for red pine appears bright, it must be constantly monitored to ensure that our goals for this resource can continue to be met.



	Michigan	Wisconsin	Minnesota	Red pine average	All species ratio
1960s	12.4	7.1	6.2	8.3	2.6
1980s	5.8	2.7	3.8	3.7	2.0
1990s	4.9	5.0	4.6	4.9	2.0

Figure 11. Average growth-to-removals ratios for red pine in the Northern Lake States.

Literature Cited

Miles, P. D., G. J. Brand, C. L. Alerich, L. F. Bednar, S. W. Woudenberg, J. F. Glover, and B. N. Ezzell. 2001. The forest inventory and analysis database: database description and users manual version 1.0. Gen. Tech. Rep. NC-218. St. Paul, MN: USDA Forest Service, North Central Research Station, 130 p.

Powell, D. S., J. L. Faulkner, D. R. Darr, Z. Zhu, and D. W. MacCleery. 1993. *Forest resources of the United States, 1992*. USDA Forest Service Gen. Tech. Rep. RM-234. 132 p.

Schmidt, T. L., J. S. Spencer, and M. H. Hansen. 1996. Old and potential old forest in the Lake States, USA. *For. Ecol. and Manage*. 86: 81-96.

Guides to Red Pine Management: Where Have We Been? Where Should We Go?

Allen L. Lundgren, (retired, USDA Forest Service and University of Minnesota)
765 Redwood Lane, New Brighton, MN 55112;
phone: 651-633-5442; e-mail: alundgren@attbi.com[1]

ABSTRACT. From 1914 to the present, red pine management guides have expanded in scope, as research programs throughout the Lake States have produced ever-increasing knowledge about red pine. Most guides to date have focused on managing individual stands of pure red pine to produce high value timber products. Although adequate for their time, most do not cover the entire range of conditions confronting forest managers in the field today. Existing guides are somewhat outdated. They give little attention to how stand management could be changed to address landscape concerns, or to meet the other nontimber goals, or multiple goals, of many owners. Current forest managers and researchers should carefully assess the need for new expanded guides, and determine what, if anything, needs to be done, how it should be done, who should do it, and when it should be done.

KEY WORDS. *Pinus resinosa*; Red pine; Management; Guides;

Where Have We Been?

The pine forests of the Lake States were critical in developing the north central region of the United States. Wood was needed for fuel, railroad ties, poles, posts, pulp, and other purposes, but lumber was the most important use. Two species, white and Norway or red pine, dominated the lumber market. You know the story of lumbering and its effects in the Lake States. When it was done, slash covered the ground. Wildfires were frequent. If regeneration did occur naturally, wildfires usually destroyed the young trees, and any hope for a future forest. For decades in the Lake States, little or no effort was made to regenerate the pine once it was cut until the Morris Act of 1902. This act provided that 5% (later increased to 10%) of the pine timber to be harvested from certain lands, which later become part of the Minnesota (now Chippewa) National Forest in northern Minnesota, was to be left as seed trees (Wales 1949). This attempt to get regeneration following logging was only partly successful (Zon 1912). Today pine, once a dominant forest type in Lake States forest

[1] Lundgren, A. L. 2002. Guides to red pine management: Where have we been? Where should we go? In *Proceedings of the Red Pine SAF Region V Technical Conference*, eds., Gilmore, D. W., and L. S. Yount, 17-25. Staff Paper no. 157. St. Paul, MN: University of Minnesota, College of Natural Resources, Department of Forest Resources.

ecosystems, is a relatively small component. Lake States' forests are not the natural ecosystems that once were here. But the interest in pine management remains.

Early forest managers in the Lake States Region gave high priority to fire protection. Yet, more than 100 years ago in his report, "*Timber Conditions of the Pine Region of Minnesota*," Horace B. Ayres from Aitkin, Minnesota, an early active SAF member, recognized the role of fire in the original forest:

> "Thus it is seen that fires are not a novelty in these old woods, but have for hundreds of years been a prominent factor in their history." (Ayres 1900, p.685)

Wildfires could be devastating. In 1878 Professor N.H. Winchell, in his Geological and Natural History Survey of Minnesota, stated:

> "It is estimated that annually ten times as much pine is destroyed [by fire] in the State as is cut by all the mills . . . The State has lost in this way more than as much pine as now remains." (Ayres 1900)

Many recognized that if you wanted to grow pine, you had to control wildfire. In preparing their 1896 report, "*Rate of Increase on the Cut-over Timber Lands of Minnesota*," Samuel B. Green and H. B. Ayres asked for the opinions of lumbermen and others about growing pine. One of those responding, Frederick Weyerhaeuser, stated: "In my opinion the only way to preserve the young pine timber in Minnesota is to make such laws as will be reasonably sure to keep all fires from destroying the young and growing timber . . . " (Green and Ayres 1896).

Michigan, Wisconsin, and Minnesota all tried to control wildfires in the 1800s, but for decades state legislatures failed to provide adequate funding. Little land was under forest management. The aim of fire fighting was to protect forests, land, and buildings owned by private individuals and firms. Many people lost their lives in major forest fires such as Peshtigo in Wisconsin and Hinckley in Minnesota, dramatizing the effects of wildfire. With this history, it is easy to understand why control of wildfire was emphasized in early forest management guides.

In 1895, C. C. Andrews was appointed Chief Fire Warden of Minnesota (Bachmann 1965). He published his first annual report the following year. Christopher Columbus Andrews was an early and vigorous apostle of forestry. In his annual reports he described not only the forest fires suppressed each year, but also the state of forestry in the U.S. and Europe (State of Minnesota 1896). Through his reports, talks, and letters he argued strongly for the adoption of forestry in the state. In his Annual Report for 1898 he printed a report, written at his request by Dr. C. A. Schenck, a well-known forester from the Biltmore estate, about the feasibility of replanting the northern pine forests of Minnesota. Dr. Schenck recommended the project. However, the state legislature was less enthusiastic about the prospects of forestry, an experience all too common in the Lake States at that time. But Andrews did influence thinking about forestry in the State. His title of Chief Fire Warden was changed to

Forestry Commissioner in 1906, with the annual reports continuing under this new title (see, for example, State of Minnesota 1908).

An Early Guide

In the early years of the 1900s little scientific forest management as we know it was applied on the ground. Industry as a whole was more interested in removing timber than growing it, and there was little public land on which to apply forestry. Although red pine was fast disappearing from the Lake States forests, Theodore S. Woolsey, Jr., and Herman H. Chapman did develop one of the earliest guides to managing red pine in 1914 (Woolsey and Chapman 1914). Published as a USDA bulletin, it was based on their own field observations and what was known about the species. In a note to the guide, the authors state:

> "The manuscript describes the life history of the Norway pine, its requirement upon soil, moisture, and climate, its rate of growth and yield, and the best methods for its management." They go on: ". . . when the present stand of timber has been depleted . . . the Norway pine will be found to be one of the few important trees of the . . . Lake States."

Who were Woolsey and Chapman? Woolsey was Assistant District Forester, District 3, with the Forest Service. Chapman was a Professor at Yale Forest School. Before that, around 1900, Chapman had been Superintendent of the University of Minnesota's North Central School and Experiment Station at Grand Rapids, Minnesota, about 70 miles northwest of here. While Superintendent, he made one of the earliest attempts to establish a pine plantation in Minnesota. In 1897 Warren Pendergast, then Superintendent, had gathered 2-to 4-year-old red pine seedlings growing in the wild just a few miles from here, and put them in transplant beds. Chapman planted them in 1900 and 1901 at 4x4, 6x6, 8x8, and 10x10 spacings on a 32-acre site in pure and mixed stands with White, Jack, and Scotch pine (Allison 1923, 1954). A wildfire in 1905 destroyed much of the stand, but several acres survived. Today, the "Chapman Plantation," as it is called, is one of the oldest red pine plantations in the Lake States. Growth and yield plots have been measured every five years since 1915. It has been thinned periodically since 1943. Obviously, H. H. Chapman had an early interest in red pine.

The Woolsey/Chapman guide recognized that seed crops of red pine, occurring only at intervals of 3-7 years, could not be relied upon for natural regeneration. Planting may be needed. It stated: "Norway has few serious enemies." "Freedom from ordinary injuries constitutes the strongest recommendation in favor of Norway pine for forest management." The guide recognized the importance of keeping the stand fully stocked to insure high timber yields, and reported observed yields of fully stocked stands. But it also recognized that in nature red pine stands are rarely fully stocked over large areas. Improvement cuttings are recommended at intervals of 15 to 25 years, by marking trees to be cut. The need to replace the stand at the end of the rotation is emphasized, and the guide suggests:

> "The aim should always be to secure a second crop by natural seeding of the ground by the trees in the original stand . . . by proper methods of cutting. Artificial sowing

or planting, because of the initial cost and . . . low stumpage prices, should be resorted to only when natural reproduction fails." It recommends growing needed planting stock in the nursery.

The authors firmly state that growing stands must have protection:

"Protection of stands from fire is obviously the first step in forest management."

I spent a lot of time reviewing this early guide to remind us that Lake States foresters have known quite a bit about managing red pine for almost one hundred years, although they did not yet have the data to quantify their recommendations. Later guides have added many details about management, but even at this early date much was known.

For example, in 1900 H. B. Ayres distinguished between the soil requirements for good growth of white pine, from that of Norway or jack pine, and of other species. In 1917 H.H. Richmond[1] remarked on the importance of soil requirements: "[The Norway Pine] type is found established on sandy soil. It requires for its best development slightly better soil and moisture conditions than Jack Pine but is not as exacting as White Pine which requires some clay in the soil." Richmond goes on to describe red pine's shade tolerance, growth and longevity, average stand diameter, height, and yield, and red pine's reproduction and susceptibility to injury. His estimates of yields, by the way, go out to 250 years.

In 1903 Michigan set aside in Roscommon and Crawford counties,

"... lands to be used for forestry purposes . . . " (State of Michigan 1917).

Although the legislature provided only limited funds to administer the land, the State began planting as early as 1904. Filbert Roth, Professor of Forestry at the University of Michigan, visited the Higgins Lake Reserve, and reported promising advances in fire protection, restocking, and other activities. He observed that of all the species planted:

"Norway pine made the best and most shapely trees . . . " (State of Michigan 1919).

Wisconsin was also active at the beginning of the century. The first annual report of the State Forester in 1906 outlined the State's forest policy, and its selection of 20 thousand acres for the creation of forest reserves (State of Wisconsin 1906).

Later Guides

During the first half of the 1900s, results of research and observations about red pine were published by the USDA Forest Service, the state governments, universities, and others, in the

---

[1] Richmond, H. H. 1917. *General silvicultural report, Minnesota National Forest*. Revised. Cass Lake, MN: USDA Forest Service, Minnesota National Forest. 36p. (Edited typed draft).

Lake States, other parts of the northeastern U.S., and by Canada. Many long-term studies got underway at this time.

In 1948, a new guide, "Red Pine Management in Minnesota," by F. H. Eyre and Paul Zehngraff (1948), was published as a USDA Circular. This 70-page guide influenced an entire generation of foresters. As with earlier guides, the emphasis was on growing red pine for timber, with special attention to intensive management through thinnings and partial cuts. It recommended a final harvest cut at age 140. Although by this time some growth and yield studies were underway, only a limited amount of information was yet available for making specific cutting recommendations.

Ten years later timber management continued to be the main objective of a series of guides produced by the USDA Forest Service for the national forests of the Lake States. The red pine guide recognized several different subtypes of red pine, but generally argued for preferring red pine when it is the major stand component (USDA Forest Service 1958). It summarized the essentials of red pine management, drawing upon the limited research that had been published since the 1948 guide.

In 1962 Dr. Robert Buckman's study, "Growth and Yield of Red Pine in Minnesota," was published as a USDA Technical Bulletin (Buckman 1962). It was one of the first attempts in this country to develop mathematical equations that could be used to predict stand growth and yield for an important timber species. He drew together data from 235 studies in Minnesota, to develop equations for projecting basal area and volume growth of red pine stands over a range of sites, ages, and basal areas, together with yield tables for those conditions. Buckman's equations made it possible for the first time to examine the effects of proposed stand cutting treatments on future growth and yields of stands, and develop improved methods of stand thinning. Dr. Buckman will be speaking later about his more recent work to update red pine growth and yield.

John Benzie used this information and other research in preparing a USDA Forest Service manager's handbook for red pine (Benzie 1977). This continued to focus on managing red pine for timber. It recognized recreation, water, and wildlife as other "resource conditions" to be considered, but made no specific recommendations.

In 1984, the University of Michigan published, "Red pine plantation management in the Lake States: A handbook." The effects of pine plantations on wildlife were recognized, but the emphasis on timber production continued.

I do not have time to review the many other formal and informal guides that have been produced in recent years as more information about red pine has become available. Of particular promise is the development of computer programs modeling red pine growth and yield, and many other programs to assist forest managers. One can only hope that continued work will be done to realize the potential of computers and the Internet in making even more information readily available to forest owners and managers.

About a year ago I developed a listing of references to red pine publications for my own use. Although I am sure it does not have everything published, it lists 647 references on 39 pages, with emphasis on management and growth and yield of red pine. Less than one-quarter were published in the seven decades before 1960. Most were published during the last four decades. Obviously we have accumulated a lot of information from research on red pine during the past century, and we are acquiring more all the time from research in both the U.S. and Canada. Still, several important questions remain unanswered.

Are Existing Guides Adequate Today?

As we have seen, many red pine management guides have been developed over the years. The question remains: Do they fit today's problems? I have no answers. All I can do is raise some questions for you to consider, based on some deficiencies I see in existing guides:

(1) Existing Guides Assume Stand Management.
Most guides to red pine management emphasize how each uniform stand should be treated, in isolation. Landscape concerns are ignored. Should management guides consider broader landscape questions?

(2) Existing Guides Address Limited Objectives.
Some guides have suggestions for producing fiber, but most focus on timber production. Little attention has been given to managing for other products or services such as recreation, aesthetics, water production and conservation, for specific wildlife or all wildlife, or other legitmate purposes. Should a guide attempt to address all of these concerns by detailed management recommendations?

(3) Existing Guides Cover a Limited Range of Conditions.
Because we have lacked quantifiable data, most guides cover a limited range of sites, ages, and stocking levels and do not cover all possible conditions under which red pine occurs. To what extent should a management guide attempt to cover all existing or possible conditions?

(4) Existing Guides Do Not Adequately Deal With Mixed Species Stands.
Although historically some of the earliest pine stands had mixtures of red, white, and jack pine, or other conifer and hardwood species, most guides apply primarily to pure red pine stands, not to stands with mixtures of species. Should mixtures of species be encouraged? If so, how should mixed stands be managed?

(5) Existing Guides May Not Fit With Ecological Classifications of Type.
To what extent should red pine management guides correspond to newer definitions of forest type, based on vegetation associations, etc.?

Where Should We Go From Here?

Much of my career was spent working with red pine. I think the species has much to recommend it. It grows fast over a wide range of conditions, tolerates a wide flexibility in management, has a relatively low mortality rate, can be used for many products, and can live to an advanced age. Along with white pine, it was a significant part of the past forest environment of the Lake States. I believe it should occupy an even larger part of the Lake States forests than it does today.

As an old forester that grew up and worked in a different environment than many of you, I have my own biases about what should be done about the future management of red pine. But decisions about new guides should be left to you, a newer generation of foresters, faced with different problems and opportunities than our generation faced. For what it is worth, I would like to see the development of new red pine management guides with more attention given to:

(1) Managing Old Growth - What methods should be used to carry trees to an advanced old age for recreation areas, aesthetics, or other purposes?
(2) Managing Stands with Species Diversity - Should we attempt to encourage a diversity of both conifers and hardwoods in stands that are predominantly red pine?
(3) Producing High Volumes of Fiber - How should stands be managed to insure a high production of wood intended for pulpwood?
(4) Addressing Landscape Issues - How can we best incorporate stand management issues into the larger forest picture?
(5) Specific Recommendations for Wildlife, Recreation, and Other Management Objectives - What changes in management are needed to better achieve nontimber objectives?

You all have your own ideas on what may be needed. But any guidelines that are produced should be based on sound information. They should be practical and easy to access and apply in the field. With the information we already have it should be possible to develop guides that better suit today's needs. However, we will undoubtedly need continued research to meet these new needs.

But are new guides with printed fixed recommendations what are really needed? They are so unchanging! So inflexible! Perhaps it is time to consider how computers and the Internet can be used more effectively to organize and transfer a rapidly changing information base to better fit the wide variations found in the field.

If you do believe new guidelines are needed, ask yourself:

What should be done? Should updated stand guides be produced? A series of guides to meet the needs of various management objectives? Perhaps it is time to take a fresh look at the whole question of the usefulness of guides.

How should this be done? Current forest managers, research scientists, and users of guides need to decide this. The process you have followed in developing Best Management Practices and other management guidelines may be helpful in creating reliable, useful guides that can be and will be applied in the field.

Who should do it? I do not know who should do it. But I do know it should not be left up to chance in the hope that somebody will do it. And it should incorporate the ideas of a wide range of potential users, and those who are affected by red pine management.

When should it be done? As Soon As Possible. I have always liked (but did not necessarily follow) the good advice of Arnold Toynbee (1960), the noted historian, who said,

> ". . . the right moment for starting on your next job is not tomorrow or next week; . . . it is . . . right now."

Literature Cited

Allison, J. H. 1923. Twenty years' growth of planted Norway, Jack, Scotch, and White Pine in north central Minnesota. *Journal of Forestry* 21(8):786-801.

Allison, J. H. 1954. *Growth of planted Norway (red) pine in Northern Minnesota*. Minnesota Forestry Notes no. 34. St. Paul, MN: University of Minnesota School of Forestry. 2p.

Ayres, H. B. 1900. Timber conditions of the pine region of Minnesota. In *U.S. Geological Survey, Twenty-first Annual Report, 1899-1900, Part V, Forest Reserves* (plus map in maps folder), 673-689. Washington, DC: U.S. Government Printing Office.

Bachmann, E. 1965. *A history of forestry in Minnesota, with particular reference to forestry legislation*. St. Paul, MN: Minnesota Department of Conservation, Division of Forestry. 109p.

Benzie, J. W. 1977. *Manager's handbook for red pine in the North Central States*. General Technical Report NC-33. St. Paul, MN: USDA Forest Service, North Central Forest Experiment Station. 22p.

Buckman, R. E. 1962. *Growth and yield of red pine in Minnesota*. Technical Bulletin no. 1272. Washington, DC: USDA Forest Service. 50p.

Eyre, F. H., and P. Zehngraff. 1948. *Red pine management in Minnesota*. Circular no. 778. Washington, DC: USDA. 70p.

Green, S. B., and H. B. Ayres. 1896. Rate of increase on the cut-over timber lands of Minnesota. In *Annual Report*, 259-304. Delano, MN: University of Minnesota, Agricultural Experiment Station.

State of Michigan. 1917. *Biennial Report of the Public Domain Commission from July 1, 1914 to June 30, 1916*. Lansing, MI: Wynkoop Hallenbeck Crawford Co., State Printers.

State of Michigan. 1919. *Biennial Report of the Public Domain Commission from July 1, 1916 to June 30, 1918*. Fort Wayne, IN: Fort Wayne Printing Company.

State of Minnesota. 1896. *Forest preservation. First annual report of the Chief Fire Warden of Minnesota for the year 1895*. St. Paul, MN: Pioneer Press Company. 188p.

State of Minnesota. 1908. *Thirteenth annual report of the Forestry Commissioner (formerly Chief Fire Warden) of Minnesota for the year 1907*. St. Paul, MN: Pioneer Press Company. 148p.

State of Wisconsin. 1906. *First annual report of the State Forester of Wisconsin: 1906*. Madison, WI: State Board of Forestry.

Toynbee, A. J. 1969. Why and how I work. *Saturday Review* (April 5, 1969):22-27, 62.

USDA Forest Service. 1958. *Timber management guide for the national forests of the North Central States: red pine type*. Milwaukee, WI: USDA Forest Service. 13p.

Wales, H. B. 1949. Evolution of management on Chippewa. In *Trees: The yearbook of agriculture, 1949*, 311-319. Washington, DC: U.S. Government Printing Office. 944p.

Woolsey, T. S. Jr., and H. H. Chapman. 1914. *Norway pine in the Lake States*. Bulletin no. 139. Washington, DC: USDA. 42p.

Zon, R. 1912. *Results of cutting on the Minnesota National Forest under the Morris Act of 1902*. Proceedings, Society of American Foresters 1912: 100-105.

Highlights---Growth and Yield of Red Pine in the Lake States

Robert E. Buckman, Professor (retired), College of Forestry,
Oregon State University, robert.buckman@orst.edu
Allen L. Lundgren, Adjunct Professor, College of Natural Resources,
University of Minnesota, alundgren@mediaone.net
Badege Bishaw, Research Associate, College of Forestry, Oregon University,
badege.bishaw@orst.edu
Dietmar W. Rose, Professor Emeritus, University of Minnesota, drose@forestry.umn.edu
and
Frank A. Benford, Consulting Mathematician, Salem, OR, benford@open.org [1]

ABSTRACT. This paper highlights in outline form the findings of an analysis now nearing completion of the entire portfolio of active and inactive red pine growth and yield studies of the USDA Forest Service North Central Forest Experiment Station and its many cooperators. Examined here are some 31 sets of data containing 3,671 separate growth estimates representing a wide range of ages, site indices and stand densities. Principal outputs of this analysis will be: (1) revised estimates of growth and yield in relations to age, site index and stand density; (2) essentially new findings of growth responses in relation to thinning methods (above, below) and crown classes, and (3) examination of several factors related to spatial arrangements of trees in stands. A revised computer simulation program is now in preparation will quantify several aspects of stand growth.

KEY WORDS. Red Pine, Growth and Yield, Stand Density, Thinning Methods, Crown Class responses.

The Data Base

- Examined here are 31 sets of experiments and growth plots in plantations and natural stands in Minnesota, Wisconsin, and Michigan, the oldest dating to the mid-1920s.
- These contain some 3671 individual growth observation representing a wide range of ages (10-190 yrs), site indices (40-75) and stand densities (30-200 ft^2 plus unthinned).
- Data is of high mensurational quality, but with substantial statistical inadequacies. When compared to independent data sets, however, growth predictions thus derived appear to be reasonably reliable.

[1] Buckman, R. E., A. L. Lundgren, B. Bishway, D. W. Rose, and F. A. Benford. 2002. Highlights–Growth and yield of red pine in the Lake States. In *Proceedings of the Red Pine SAF Region V Technical Conference*, eds., Gilmore, D. W., and L. S. Yount, 25-31. Staff Paper no. 157. St. Paul, MN: University of Minnesota, College of Natural Resources, Department of Forest Resources.

Principal Findings

Stand age[1]

- Good estimates of stand growth available between ages 20 and 200.
- More rapid growth between ages 6 and 25 than previously thought, but estimates are less reliable.
- Opportunity for new look at silviculture in this age range, especially where high biomass production is goal (Also see stand density below, bullet #5).

Site index and stand height[2]

- Much studied—reasonable estimating procedures available. We use a slightly modified version of the Gevorkiantz and Lundgren/Dolid site index (SI) curves.
- Once SI is known to dominate stand height can be estimated at any age (average dominant height, multiplied times stand basal area and a coefficient provide good estimates of stand volume—i.e., 0.4085 x basal area x average dominant height is used here to estimate stand cubic-foot volume).
- Stand yields (thinning plus standing volume) approximately double from SI 45 to SI 75.
- High SI is one of the most sensitive indicators of economic profitability in red pine management, despite generally higher costs on better sites.

Stand Density[2]

- Height growth of the dominant stand is unaffected over the wide range of stand densities commonly used in red pine management.
- In young stands (age <20-25) stand growth is strongly affected by numbers of trees per acre. Beyond ages 20-25 numbers of trees have far less predictive value for stand growth, and basal area becomes a more useful expression of stand density.
- Individual tree growth (as contrasted to stand growth), however, is strongly affected by tree numbers at all ages.
- Beyond age 25 basal area growth is approximately equal over a wide range (ca 100-200 ft^2) of stand densities.
- Cubic volume growth increases with higher stand densities, more so on better sites and at younger ages, when height growth is most rapid.
- Prompt and successful establishment of new stands, and aggressive release from competing vegetation (i.e., aspen, birch, oaks, hazel), greatly favors red pine growth and weighs strongly and positively in economic analyses.

Stand Mortality[2]

- Of the 3,671 growth observations, 75 percent had zero mortality.

---

[2] Indicates quantitative estimates of growth in relation to each variable is available in a computer-based algorithm tentatively labeled RP2002 (see RP2002 below).

- Some 907 observations, about 25 percent of total, experienced mortality ranging from near-zero to about 5 ft^2 /acre/yr. Three observation suffered catastrophic losses.
- Overall mortality (excluding catastrophic losses) averaged about 1 percent of gross basal area growth, somewhat greater in high density and older-aged stands, substantially lower than average otherwise.
- Catastrophic mortality very difficult to estimate, but should be anticipated in layout and management of stands (i.e., fire and wind vulnerability, animal damage, excessive stand densities, beyond say >200ft^2/acre).

Thinning Methods—(above, below, combination)

- Up to midrange densities (ca 120 ft^2) thinning-from-above consistently outperforms (but with considerable variability) thinning-from-below, more so at low- than at midrange densities (see table 5.2.1).
- Little growth difference among thinning methods in densities >120 ft^2.
- Repeated thinning from above reduces dominant height (ca 2-5 ft), but with small consequences on stand growth.
- Substantial takeoffs in size of trees harvested and those remaining, affording many silvicultural and economic options now and in future (see table 5.2.2)

Crown class responses (helps explain thinning methods findings)

- At low densities (< 120 ft^2) intermediate and smaller codominant trees capture larger share of stand growth.
- At midrange densities (ca 120-160 ft^2) growth is approximately equal among crown classes.
- Above 160 ft^2 (including no thinning) growth shifts toward dominant crown classes, with smaller classes falling behind and eventually dying.

Spatial Relationships

- For stands of comparable residual densities, no differences in growth rates between uniformly-spaced and row-thinned stands.
- For stands of comparable residual density, intensity of thinning (removal of up to 2/3 of stand in a single thinning) has little impact on future growth.
- Variability of tree diameters (presumably an indicator of uniformity of tree spacing) has no predictive value for stand growth.
- Strong suggestions that underground processes (wide-spreading root systems, symbiotic fungi, root grafts) explain many growth responses.

Table 5.2.1. Cumulative net and gross basal area growth for four long-term methods-of-thinning studies in red pine.

Basal area after thinning	Number of thinnings	Basal Area Growth When Thinned From:							
		Below		Above and below		Above		Above as a percent over below	
		Net	Gross	Net	Gross	Net	Gross	Net	Gross
ft^2/Acre	Number	ft^2/Acre						Percent	
		Cutfoot -- 45 Year Summary							
100-120	4-5	80.8	82	89.7	93.1	111.9	115.5	38	41
		Birch Lake--- 35 Year Summary							
30	2	52	52.4	65.7	65.7	64.9	71.8	25	37
60	2	87.3	88.6	100.6	104.3	106.2	111.6	22	26
90	3	95.7	95.7	101.8	104.5	110.8	112.3	16	17
120	3	101	101	93	112.9	108.1	110.1	7	9
150	3	113.8	114.8	102.3	111	110.4	114.1	-3	-1
unthinned	None	--Net 88.7		--Gross 111.5			----	--	-
		Sooner Club -- 37 Year Summary							
30	2	89.7	91	--- No Treatment ---				--	--
60	2	147.5	147.5	145.5	147	170.9	171.9	16	17
90	3	172.3	172.3	166.5	167.1	175.1	181.3	2	5
120	3	169.3	169.9	148.5	166.4	175.8	181.2	4	7
150	3	165	177.3	--- No Treatment ---				--	--
unthinned	None	-- Net 57.3		--Gross 146.1					
		Bosom Field -- 36 Year Summary							
90-120	4	144.2	144.6	-- None --		161.3	174.3	12	21

Table 5.2.2. Changes in mean tree diameter and numbers of trees per acre for four long-term methods-of-thinning experiments.

Basel area after thinning	Number of thinnings	Mean dbh and Numbers of Trees When Thinned From:											
		Below				Above and Below				Above			
		1st Thinning		Most recent measurement		1st Thinning		Most recent measurement		1st Thinning		Most recent measurement	
		Before	After			Before	After			Before	After		
ft²/acre	Number	DBH - inches			Number	DBH - inches			Number	DBH - inches			Number
		Cutfoot --- 45 Year Change											
100-120	4-5	9.7	10.3	17	87	9.3	9.7	16	99	9.1	8.7	13	156
		Birch Lake --- 35 Year Summary											
30	2	8	9.2	17	50	8.1	8.8	17	58	7.8	6.4	13	100
60	2	8.4	9.7	16	93	8.1	8.4	15	125	8.3	7.2	12	178
90	3	8	9	15	95	8	8.4	14	107	7.8	7.4	12	163
120	3	8.2	8.9	13	148	8.1	8.4	13	148	8.2	7.9	11	208
150	3	7.6	8.1	12	223	7.8	7.9	12	237	8.1	8	11	277
unthinned	none	Beginning DBH 8.3 inches--most recent DBH 11.1 inches, 398 trees/acre											
		Sooner Club --- 37 Year Summary											
30	2	4.8	6.3	16	70	-- No Treatment --							
60	2	4.8	5.7	12	200	4.9	5.1	12	213	4.9	4.3	11	317
90	3	4.8	5.6	12	140	4.9	4.9	12	167	4.7	4.4	9	287
120	3	4.8	5.3	10	287	4.5	4.5	11	257	4.6	4.5	8.4	427
150	3	4.7	4.7	9.8	375	-- No Treatment --							
unthinned	none	Beginning DBH 5.3 inches--most recent DBH 8.4 inches, 573 trees/acre											
		Bosom Field --- 36 Year Summary											
90-120	4	6.3	6.7	14	NA	-- No Treatment --				5.2	4.7	8.5	NA

[1]Small anomalies in tree numbers and tree sizes resulted from two thinnings at 30 and 60 ft. Treatments as contrasted to three thinnings for 90 ft. and higher densities.

RP2002

- A computer-based model, now in preparation, to simulate stand growth and yield.
- Intended to track stand growth and average tree sizes through time in response to a variety of silvicultural options.

Important Unfinished Business

- Reliable techniques for natural regeneration in existing stands.
- Restoration of pine to former sites, especially on better quality lands.
- Landscape consequences of conifer restoration on now-hardwood dominated landscapes.
- Better quantitative growth estimators for cutting methods/crown class responses.
- Improved estimates of growth in vicinity of culmination of PAI (ca. ages 15-25).
- A better understanding of belowground growth processes.

New Century—New Biophysical Information and New Strategy for Managing Red Pine

Donald H. Prettyman, Scientist-Biophysics, Natural Resource Services, Limited,
2323 East Third Street, Duluth, MN 55812, histicdp@msn.com; and
Garrett Ous, Land Commissioner, Itasca County Land Department,
123 NE 4th Street, Grant Rapids, MN 55744, garrett.ous@co.itasca.mn.us [1]

ABSTRACT. New objective and verifiable biophysical data collected from several thousand 1/50th fixed radius sample points within rectangular 10-point cluster (10 acre) stratified random plots in forest land in northern Minnesota revealed significant biophysical variability beneath red pine canopies. The data showed high quality red pine growing in dry sandy, clayey, acid and calcium-rich root zones. Beneath the red pine-dominated canopy was substantial biophysical variability that revealed a wide range of shrubs, forbs, mosses, and grasses. The morphology of plant communities included distinct multilevel shrub and forb layers and contrasting park-like condition. New biophysical data supported new biophysical information that identified new opportunities for managing red pine. That new information will substantially increase the predictability of prescriptive forest land management and significantly reduce the risk of adverse results.

KEY WORDS: New biophysical information, biophysical variability and new management opportunities.

Introduction

Red pine (*Pinus resinosa* Ait.) has a reported natural range extending throughout the Lake States and New England (Little 1971, Buckman 1962). Red pine is somewhat tolerant to shade and is generally associated with dry sandy land. It occurred in pure stands and in mixtures with jack pine, white pine, fir, spruce and hardwoods. Sandy land in Wisconsin with oxygen-rich water at depth of 4 to 9 feet (subirrigated) substantially increased growth and yield of red pine (Wilde 1965) and the same has been identified in northern Minnesota via biophysical system. Red pine is intolerant to prolonged moist and wet conditions in root zone.

The biophysical system uses objective and verifiable data collected at multipoint plots that are oriented across landscape contours for characterizing biophysical properties (Prettyman 1994). Biophysical information for northern Minnesota substantially increased land managers understanding of the forest land, its environment and its natural biophysical

---

[1] Prettyman, D. H., and G. Ous. 2002. New century–new biophysical information and new strategy for managing red pine. In *Proceedings of the Red Pine SAF Region V Technical Conference*, eds., Gilmore, D. W., and L. S. Yount, 32-43. Staff Paper no. 157. St. Paul, MN: University of Minnesota, College of Natural Resources, Department of Forest Resources.

variability. It demonstrates that red pine has moderate to high yields with sandy to clayey root zones and acid to calcium-rich root zones. Biophysical information has revealed the influence of climate on growth of red pine growing in similar root zone at different geographic locations (Prettyman 1992). That information provides forest land managers with new opportunities for managing red pine and significantly increases acreage capable of growing quality softwood products. That biophysical information, produced by custom designed program directed by organization's staff, demonstrates the benefit of timely combination of applied science with tactical and strategical management. Such a combination linked with qualified and quantified biophysical variability presents new opportunities for managing red pine stands for sustained supply of quality wood products, for improved scenic quality, for maintaining flow of quality water from forest land and for increasing diversity of wildlife habitat.

In Itasca County, the Land Department began a program in 1995 using the biophysical system (Prettyman 1998) that provides a base of objective verifiable biophysical data collected from stratified random multipoint plots for characterizing forest land. Biophysical properties were characterized based on detailed data collected from 2650 1/50th acre fixed radius sample points from 265 rectangular 10-acre plots. Each plot had 10 fixed radius points. Each plot was oriented across landscape contours to maximize interception of natural variation of biophysical properties (Prettyman 1994). For this discussion of red pine and associated biophysical properties, 108 1/50th acres sample points from 43 plots were selected.

A modified fractal model was used for analyzing the biophysical data. The properties represented by that data are the axiomatic base that becomes the foundation for obtaining an effective and realistic understanding of inherent biophysical variability of forest land that is important for managing red pine. Stratification of the objective and verifiable biophysical data was done in preparation for use of routine statistical analytical methods. Basic fractal theory and geometric models have been utilized extensively in geology (Bartoli et al. 1991; Burrough 1983; Garrison et al. 1992; Krohn 1988; Muller et al. 1990; Tyler and Wheatcraft 1990; Young and Crawford 1991), in geographic feature descriptions (Chase 1992; Goodchild and Mark 1987), in interpolation of subsurface hydrology (Molz and Boman 1993), in ecology to characterize vegetation structure (Cohen et al. 1990; Palmer 1988; Rex and Malanson 1990) and to describe landscape patterns (Burrough 1981; DeCola 1989; Frontier 1987; Krummel et al. 1987; Loehle and Wein 1994; Milne 1990; Warner and Fry 1990).

A brief description of each biophysical region in which plots were located is presented next in this paper for additional background information pertinent to red pine growth and yield. Each biophysical region has definitive biophysical variability that can be quantified and qualified with new data. That variability represents a unique combination of geology, geomorphology and climate for each region and boundaries between regions are highly visible to forest land managers. Within the forest land where biophysical plots were located, the Des Moines glacial lobe about 10,000 years ago deposited extensive nutrient-rich earthen materials with high levels of calcium, silt and clay in which the current root zones developed

(Hobbs and Goebel 1982). At about the same geologic time, the Rainy glacial lobe deposited less extensive deposits of earthen materials with low to moderate levels of nutrients, high level of sand and low to moderate levels of silt and clay. An analysis of climate data from certified weather stations revealed a warming trend from north to south through the project area and a drying trend from east to west through the area. There are numerous micro sites with specific microclimate throughout the forest land in which the plots were located. Those sites include north aspects with low frequency of warming and cooling and wetting and drying, south aspects with high frequency of heating and cooling and wetting and drying and greater extremes in differences than the north aspects, depressions in landscape that collect cold air, depressions that seasonally fluctuate from dry to flooding, foot slopes that receive moisture and nutrients from up slope positions, narrow ridges that loose significant amounts of moisture and nutrients to lower slopes and margins of uplands affected by large water bodies or large bogs (Geiger 1965; Landsberg 1958; Defant 1951; Davis 1958; Van Arsdel 1965; Lyons 1966) . All of those micro sites affect the growth of red pine and associated plants in a community and increases or decreases growth and survival of plants.

For the purpose of this report, four biophysical units dominated by red pine will be discussed and associated biophysical properties will be described. Morphology of plant community, species composition of plant community, natural moisture condition in root zone, uniformity of root zone, soil textures and inherent fertility are the principal biophysical properties that distinguished the four units. All four units were characterized using data from the Bigfork-Cook Plain, Grand Rapids Upland, and Laurentian Upland North biophysical regions that represent a major portion of the County. Red pine units 2 and 4 have contrasting site quality and contrasting biophysical properties and will be used for comparison of management opportunities for red pine.

Biophysical Regions

Bigfork-Cook Plain

The Bigfork-Cook Plain (BCP) biophysical region occupies 377,972 acres and is located along the north and northeast boundary of Itasca County. This region extends into adjoining Koochiching and St. Louis counties. Human population is low and is scattered along major roads and in small villages. Annual average precipitation is 26 inches of which 15 inches occurs May through August. Annual average temperature is 38°F and an average of 60°F for the period of May through August. Glacial drift is dominated by nutrient-rich gray materials deposited by the Des Moines lobe that moved into the region from the north and northwest. There are inclusions of scattered glacial materials from the Rainy lobe that moved into the area from the northeast. Glacial moraines, lake plains, beaches and outwash plains are common in this region. A terrain with low slope gradients combined with local contrasting steeper slopes is characteristic of land in BCP. A few bedrock outcrops occur in the eastern portion of this biophysical region. There is extensive land with numerous moist and wet depressions and local areas with dry depressions. Runoff is substantial due to the extensive deposits of slowly permeable silty and clayey materials. A considerable amount of ground water recharge occurs in the deep sandy glacial materials. Root zones in BCP are some of the most fertile in Itasca County, major factors limiting growth of plants are climate or wetness.

Grand Rapids Upland

The Grand Rapids Upland (GRU) biophysical region occupies 432,066 acres in the central part of Itasca County. This region is contained within the county and has the highest concentration of population. That population is located in Grand Rapids, other small towns and around the many lakes. Average annual precipitation is 26 inches of which 14 inches occurs during the period of May through August. Average annual temperature is 39°F and the average temperature for the period of May through August is 62°F. Glacial deposits from the Des Moines lobe prevail in this region and typically are loamy over sand and gravel. Local deposits of silt and clay are common. Glacial moraines with low rolling hills, numerous dry or moist depressions, numerous lakes and local outwash plains characterize GRU. Rock fragments are common in selected portions of the region. This region has the most open water of all biophysical regions and the pervious glacial materials potentially contribute substantial amounts of water the ground water systems. Fertility of root zones is moderate to high.

Laurentian Upland North

The Laurentian Upland North (LUN) biophysical region occupies 241,112 acres in the central and east central portions of Itasca County. This region extends into adjoining St. Louis County. Laurentian Upland North is located near the iron range; consequently, there is considerable human population in small towns and along rural roads. Average annual precipitation is 29 inches of which 15 inches occurs during the period of May through August. Average annual temperature is 35°F and the average temperature for period of May through August is 59°F. Glacial deposits from the Rainy lobe that came into the region from the north and northeast have a major influence on the root zones. Rock fragments are common in a significant portion of the region. Deposits from the Des Moines lobe are also present and often are buried beneath the Rainy deposits. Glacial outwash plains and moraines are common and the terrain varies from low slope gradients to local steep slopes associated with ice block depressions and thin glacial materials underlain with bedrock. Small lakes are scattered throughout the region and streams are common. The pervious glacial materials contribute substantial amounts of water to ground water systems. Fertility of root zones ranges from low to moderate.

Red Pine Units

Using objective and verifiable data from the stratified random plots and modified fractal model, four red pine units were identified and described for this paper. Biophysical properties important for plant growth, morphology of plant communities, indicator plants and plant species richness are presented for each unit. Preliminary analysis of biophysical data for this paper showed red pine growth patterns similar to what Wilde (1965) reported. Uniform dry sandy root zones have rapid juvenile growth followed by decreased rate of growth in contrast to root zone with loamy over clayey where juvenile growth can be slow until roots reach the nutrient-rich clayey material after which growth can increase substantially. Those interested in additional details for root zone properties, plant species lists and similar information should feel free to contact the authors with their specific requests.

Red Pine Unit 1

The red pine unit is based on biophysical properties that include dry loamy (20 inches or less) over sandy root zone. Major historical disturbances are associated with logging and fire. Glacial deposits from the Des Moines lobe occupy 80 percent of the forest land where this unit occurs. Outwash plains and moraines are the most common glacial landforms. Water saturated condition in the root zone is consistently below five feet. Rock fragments on the ground surface are uncommon in a majority of sites. Slope gradients average about 9 percent. The root zone of this unit is subject to deep leaching of nutrients because of the rapid infiltration, rapid permeability, low content of colloidal materials and low chemical exchange capacity. Nitrogen, calcium, magnesium, potassium and certain micronutrients are particularly prone to potential deep leaching (Bear 1964; Tisdale and Nelson 1966).

Plant community structure has distinct layers of woody and herbaceous plants. A representative plant community consists of a dominant red pine canopy of greater than 40 percent. There is a codominant tree canopy of 10 to 40 percent with mix of birch, aspen and balsam fir. There is a tall (6 to 25 feet) shrub canopy of 70 to 100 percent dominated by beaked hazel. There is an intermediate (3 to 6 feet tall) shrub canopy of 10 to 40 percent dominated by beaked hazel. There is a short (less than 3 feet tall) shrub canopy of less than 10 percent dominated by raspberries. There is a tall (greater than 18 inches tall) forb canopy of less than 10 percent and dominated by bracken fern. There is a short (less than 18 inches tall) forb canopy of 40 to 70 percent and dominated by asters and Lily-of-the-valley. Indicator species include beaked hazel, raspberries, violets, twisted stalk and starflower. Species richness is 42. An average site index for red pine is 58 and an average volume is 63 cords per acre.

Red Pine Unit 2

This red pine unit is based on biophysical properties and has dry and droughty coarse sandy mixed with gravel root zone. Logging, fire, and wind were common disturbances. Glacial deposits from the Des Moines lobe occupy more than 85 percent of the forest land where this unit is common. Rainy lobe deposits occur as scattered inclusions. Outwash plain is the most common landform followed by moraines and till plains. Water saturated condition in the root zone is consistently below five feet. Rock fragments on ground surface are very uncommon. Slope gradients average 5 percent. Because of the very rapid rates of infiltration and permeability, extremely low content of organic matter and colloidal and extremely low chemical exchange capacity, the root zone in unit 2 is at high risk for loosing substantial amounts of nutrients to deep leaching by percolating water.

Plant community structure has distinct tree canopy and weakly expressed lower levels. A representative plant community consists of dominant tree canopy of 40 to 100 percent and dominated by red pine. There is a codominant tree canopy of 10 to 40 percent and can include birch, red maple, aspen and fir. There is a tall shrub canopy of 10 to 40 percent that is dominated by hazel. There is an intermediate shrubs canopy of less than 10 percent and is dominated by hazel. There is a short shrub canopy of less than 10 percent and includes hazel, bush honeysuckle and blueberry. There is a tall forb canopy of 10 to 40 percent and is dominated by bracken fern. There is a short forb canopy of 10 to 40 percent and includes asters, bunchberry and Lily-of-the-valley. Indicator species include hazel, bush honeysuckle, blueberry, and wintergreen. Species richness is 37 (see also figure 1 – Red Pine Unit 2). An average site index for red pine is 62 and an average volume is 32 cords per acre.

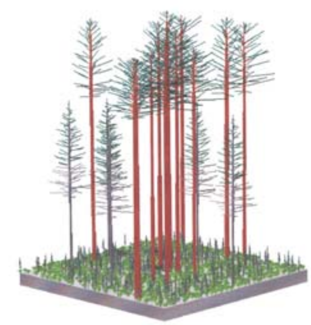


Figure 1. Red Pine Unit 2.

Red Pine Unit 3

This red pine unit is based on biophysical properties that include dry fine sandy root zone. Major historical disturbances include logging and fire. Glacial deposits are dominated by materials from Des Moines lobe with minor inclusions of materials from the Rainy lobe. The most common landform is outwash plain and less common is a till plain or moraine. Water saturated condition in the root zone is consistently below five feet. Rock fragments on ground surface are uncommon. Average slope gradient is 5 percent. The root zone in this unit will loose nutrients to deep leaching as result of rapid rates of infiltration and permeability, low level of colloidal materials and organic matter and low chemical exchange capacity.

Plant community structure has very distinct layers of woody and herbaceous plants. A representative plant community consists of a dominant tree canopy of 40 to 100 percent that is dominated by red pine. There is a codominant tree canopy of 10 to 40 percent that is dominated by red maple. There is a tall shrub canopy of 70 to 100 percent and is comprised of hazel, mountain maple and green alder. There is an intermediate shrub canopy of 10 to 40 percent and is comprised of hazel. There is a short shrub canopy of 10 to 40 percent and is comprised of hazel, bush honeysuckle and blueberry. There is a tall forb canopy of 10 to 40 percent and is comprised of sarsaparilla and bracken fern. There is a short forb canopy of 40 to 70 percent. Indicator species include beaked hazel mixed with mountain maple, green alder and serviceberries, clintonia and fringed milkwort. Species richness is 59. An average site index for red pine is 63 and an average volume is 67 cords per acre.

Red Pine Unit 4

This red pine unit is based on biophysical properties that include dry loamy and sandy (about 30 inches thick) over clayey root zone. Major historical disturbances include logging and fire. Materials from Des Moines lobe with minor inclusions from Rainy lobe dominate glacial deposits. Outwash plain underlain with clayey materials is the dominant landform. Water saturated condition in root zone is mainly below five feet but perched water does occur above four feet and is correlated with depth to clayey material. Average slope gradient is 2 percent. Loss of nutrients to deep leaching will be minimal in the root zone of unit 4 because of slow infiltration and permeability rates, moderate to high content of colloidal material, moderate level of organic matter and moderate to high chemical exchange capacity.

Plant community structure has distinct layers of woody and herbaceous plants. A representative plant community consists of a dominant tree canopy of 40 to 100 percent and is dominated by red pine. There is a codominant tree canopy of 10 to 40 percent and that includes birch, red pine, white pine, white spruce and balsam fir. There is a tall shrub canopy of 40 to 100 percent and includes dogwood, mountain maple, hazel, serviceberries, and hazel. There is an intermediate shrub canopy of 10 to 40 percent and includes a mixture of species. There is a short shrub canopy of less than 10 percent and includes bush honeysuckle, raspberries and blueberries. There is a tall forb canopy of 40 to 70 percent and includes sarsaparilla and bracken fern. There is a short forb canopy of 40 to 100 percent and includes asters, strawberry and anemone. Indicator species include mountain maple, honeysuckle, dogwood and bedstraw. Species richness is 61. An average site index for red pine is 64 and an average volume is 72 cords per acre.

Management Analysis and Implications

For decades, forest land managers were in dire need of a replacement for the outdated and inadequate component inventories and physical resource surveys and this biophysical system is a beginning of an effective replacement. This biophysical system is customized according to organizational specifications and provides new objective and verifiable data that is specific to a geographic forest land managed by the organization. Information prepared from that new data is reported to each organization annually. Reports are customized per specific topics or questions presented by each organization. A very effective training program for practicing foresters has been developed by several organizations using this new biophysical information. The results of that training clearly demonstrate the effectiveness of the biophysical information for substantially increasing foresters understanding of the forest land for which they are responsible. The confidence gained from that training has increased their effectiveness in operational dealings with contractors and in communicating forest land management topics to local citizens and visitors to the forest.

Based on a preliminary analysis of the new biophysical data and new information for red pine plant communities in forest land management by Itasca County Land Department, it is clear that there is a substantial degree of contrasting biophysical variability. Included in that variability is substantial diversity of plant communities and distinctly contrasting root zones. That biophysical variability integrated with silviculture principles and practices presents foresters with a number of meaningful opportunities for providing citizens with sustainable supply of quality forest products. The new biophysical information will substantially increase forest manager’s knowledge of the forest land and red pine communities. That new information will be a significant support factor for increasing public trust in those managers abilities, knowledge and skills necessary for prescriptive quality land stewardship and continuous supply of high quality forest products.

Myths that are put to rest following an analysis and review of the biophysical data used in the preparation of this paper are: (1) Red pine does grow vigorously in root zones with silt plus clay content exceeding 60 percent. (2) Red pine does grow vigorously in nutrient-rich root zones with pH exceeding 7.0. (3) Red pine does grow vigorously in root zone rich in calcium and magnesium and with elevated levels of silt and clay. (4) Is there such a "thing" as a red pine site or are there contrasting sites in forest land that can produce equal or contrasting rates of growth of native trees. (5) Plant communities with dominant red pine canopy are "monotypes." Putting to bed myths that red pine does not grow "well" in clayey root zone, in root zone with high pH or root zone rich in calcium and that red pine types are monotypes has opened new opportunities for interested forest land managers.

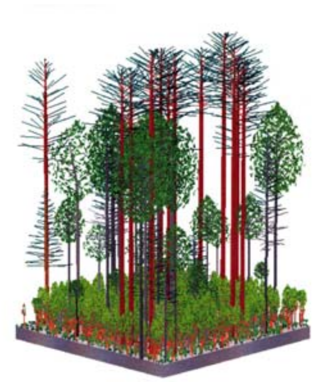


Figure 2. Red Pine Unit 4.

Wood Supply

In northeastern Minnesota, the renewable wood resource has and will continue to play a major role in the vitality of local and regional economies. Good paying jobs in many local communities are directly and indirectly associated with managing, harvesting and processing forest products. With the drastic decline in heavy metal industrial jobs in the last two decades, the importance of more fully utilizing this renewable wood resource for providing local citizen with secure and good paying jobs is of utmost importance. The new biophysical information applicable to managing red pine will support a sustainable supply of quality wood and is an important factor in securing good paying jobs for local citizens.

Climate is believed to be the major controlling factor for red pine growth in a biophysical region. That growth is then modified by conditions of the forest land that include inherent fertility in the root zone, aspect, position on the landscape and specific local conditions of micro sites (Prettyman 1992). In that portion of Itasca County that is represented in this paper, red pine biophysical unit 4 has the highest potential growth and yield followed in decreasing order by unit 3, 1, and 2. Unit 4 has the highest potential for high yields for all trees native to the area. In contrast, unit 2 has the lowest potential and nutrient-demanding trees would not be a viable alternative for sustained production of quality wood. Unit 4 with its higher level of yield should be considered for higher stocking levels of red pine than the other units and especially unit 2.

Based on estimated fertility for each unit and current technology, unit 4 has no restrictions for nutrient displacement using current rotations for red pine. However, unit 2 would require nutrient conservation measures including leaving buds, branches and leaves scattered over the area from which wood products were harvested. Nutrient conserving trees that have the physiological makeup for producing sustainable quality wood such as jack and red pine would be part of a nutrient conservation prescription for unit 2. Nutrient demanding native trees will be less desirable for producing wood products unit 2 for nutrient conservation, but might be very appropriate and acceptable for use to improve wildlife habitat or visual quality.

All units can support frost-free harvest during normal weather conditions. During periods of above average rain, unit 4 with the clayey substratum can become saturated with water above the clayey material and could restrict certain types of equipment traffic. The duration of saturation during a growing season is usually quite short because of evapotranspiration and rapid to moderate permeability of the loamy and sandy material above the clayey material.

Wildlife

New wildlife management strategies are concerned with the complexity of biophysical variability caused by natural systems or forest land management activities (Trauger and Hall 1992). New biophysical information prepared by Itasca County Land Department staff and integrated with silviculture addresses those strategies. All red pine units have high potential for providing thermal and protective cover for mammals native to the area. Richness of food plants would be highest in unit 4 and lowest in unit 2. With a nearly closed tree canopy, unit 4 can supply nuts and fruits from hazel, mountain maple, dogwoods, serviceberries, raspberries, and blueberries. In contrast, unit 2 could supply low stocking of hazel and blueberries. Openings in unit 4 would quickly fill with tall shrub and intermediate shrubs. In sharp contrast, short and intermediate shrubs would be common in unit 2. Unit 4 will have distinct layers of woody plants and forbs. The canopy density of those layers of plants will be moderate to high. In contrast, unit 2 will have a distinct dominant tree canopy and forb layer canopies of moderate to high density but very low density canopies in the space between the tree canopy and forbs. Unit 2 will be an "open" plant community, whereas unit 4 will have an abundance of woody and forb biomass beginning at forest floor and continuing into the dominant tree canopy. Following logging, fire or wind damage, unit 4 would have high species richness whereas unit 2 would have less and its species richness would tend to be short lived. Subsequently, unit 4 offers more potential life forms than the contrasting unit 2 and the former would support a larger population of ruffed grouse and songbirds than unit 2 (Martin et al. 1951). Unit 4 would provide a significant amount of biomass for browsers throughout the year. Unit 2 would be very favorable for wildlife preferring an elevated red pine canopy with no obstructions beneath to forest floor.

See figures 1 and 2 for comparison of plant communities in the respective units. Unit 4 has high potential for productive managed food plots for wildlife and unit 2 has low potential. Unit 4 has a high estimated level of major nutrients, micronutrients and a favorable pH for a wide range of plants that could produce a substantial amount of forage, flowers and fruit throughout the growing season and winter browse for selected mammals. Such open food plots would also attract an abundance of insects that would add to the variety of foods available for forest birds and mammals. Unit 4 has high potential for providing a variety of combinations of structure in a stand and that can be accomplished with current silviculture practices. Unit 2 has high potential for providing an elevated tree canopy with little structure above six feet. Unit 2 can also provide contrasting habitat when combined with unit 4.

Recreation

Figure 3. Red Pine Unit 4 and autumn colors.

Natural plains interspersed with low rolling hills occupied by plant communities with dominant red pine canopy afford numerous opportunities for high quality dispersed recreation activities for local citizens and visitors to the forest. Red pine biophysical unit 4 has enormous potential for providing rich autumn colors of red, orange, yellow and green (of pine canopy) in multilayers (see figure 3). Unit 2 will provide primarily yellow in forbs and short shrubs just above forest floor along with the green pine canopy. Both units have potential for rich hiking experiences and all-season trail activities. Native earthen materials are well suited for trail surfaces and will dry quickly following summer rain. Those materials will proved favorable driving surfaces for unpaved forest roads and afford local citizens and visitors opportunities for enjoyable auto tours through the forest land. Upland birds and game will be more common in unit 4 with its larger variety and volume of foods, dense cover and increased structure in the plant community.

Water

All red pine units produce high quality water that is typical of most forest land. Units 1, 2, and 3 have very rapid and rapid infiltration and permeability rates and during spring and fall recharges will contribute substantial volumes of water to deeper ground water systems. Unit 4 with the clayey earthen materials within 3 feet of ground surface and associated moderate to slow rates of infiltration and permeability can produce significant amounts of surface runoff and contributions to perched water systems and springs. Evapotranspiration during the growing season equals or exceeds precipitation, consequentially contribution of water to deep and shallow water systems will be minimal. Plant growth in red pine unit 2 is severely limited by lack of sufficient soil moisture. In units 1 and 3 it is also believed to limit plant growth but not to the magnitude as in unit 2. However, soil moisture in unit 4 is not a limiting factor for plant growth due to the substantially greater water holding and retention capacity of earthen material that dominates the root zone.

Literature Cited

Bartoli, F., R. Philippy, M. Doirisse, S. Niquet, and M. Dubuit. 1991. Structure and self-similarity in silty and sandy soils: The fractal approach. *J. Soil Science* 42:167-185.

Bear, F. E. 1964. *Chemistry of the Soil*. New York, NY: Reinhold Pub. Corp.

Buchman, R. E. 1962. Growth and Yield of Red Pine in Minnesota. Lake States Forest Exp. Sta. USDA.

Burrough. P. A. 1981. Fractal dimensions of landscapes and other environmental data. *Nature* 294:240-242.

Burrough, P. A. 1983. Multiscale sources of spatial variation in soil: I. Application of fractal concepts to nested levels of soil variation. *J. Soil Science* 34:577-597.

Chase, C. G. 1992. Fluvial landsculpting and fractal dimension of topography. *Geomorphology* 5:39-57.

Cohen, W. B., T. A. Spies, and G. A. Bradshaw. 1990. Semivariograms of digital imagery for analysis of conifer canopy structure. *Remote Sens. Environ*. 34:167-178.

Davis, H. W. 1958. Effect of Orange Lake on WinterTime Temperatures. Unvi. of Fla. Agr. Expt. Sta.

Defant, F. 1951. *Local Winds. Compendium of Meteorology*. Boston, MA: Am. Meteror. Soc.

Geiger, R. 1965. *Climate Near the Ground*. Cambridge, MA: Harvard Press.

DeCola, L. 1989. Fractal analysis of a classified landsat scene. *Photogrammetric Engineering and Remote Sensing* 55:601-610.

Frontier, S. 1987. Applications of fractal theory to ecology. In *Developments in Numerical Ecology*, eds., Legendre, P., and L. Legendre, 335-378. Berlin: Springer-Verlag.

Garrison, J. R., Jr., W. C. Pearm, and D. U. von Rosenberg. 1992. The fractal menger sponge and Sierpinski carpet as models for reservoir rock/pore systems: I. Theory and image analysis of Sierpinski carpets. *In Situ* 16:351-406.

Goodchild, M. F., and D. M. Mark. 1987. The fractal nature of geographic phenomena. *Annals of the Association of American Geographers* 77:265-278.

Hobbs, H. C., and J. E. Goebel. 1982. Geologic Map of Minnesota, Quaternary Geology: Minnesota Geological Survey State Map Series 5-1.

Krohn, C. E. 1988. Fractal measurements of sandstones, shales, and carbonates. *J. Geophysical Research.*

Krummel, J. R., R. H. Gardner, G. Saugihara, R. V. O'Neill, and P. R. Coleman. 1987. Landscape patterns in a disturbed environment. *Oikos* 48:321-324.

Landsberg, H. 1958. *Physical Climatology*. DuBois, PA: Gray Printing Co.

Little, E. L., Jr. 1971. Botanical Range for Trees Common in Minnesota. In *Atlas of United States Trees.* USDA Forest Service Misc. Pub. no. 1146, 3/71.

Loehle, C., and G. Wein. 1994. Landscape habitat diversity: A multiscale information theory approach. *Ecological Modelling* 73:311-329.

Lyons, W. A. 1966. Some effects of Lake Michigan upon Squall Lines and Summertime Convection. Great Lakes Res. Div. Pub. 13.

Martin, A. C., H. S. Zim, and A. L. Nelson. 1951. *American Wildlife & Plants: A Guide to Wildlife Food Habits-the use of trees, shrubs, weeds, and herbs by birds and mammals of the United States*. New York, NY: Dover Pub., Inc.

Milne, B. T. 1990. Lessons from applying fractal models to landscape patterns. In *Quantitative Methods in Landscape Ecology*, eds., Tumer, M. G., and R. H. Gardner. New York, NY: Springer-Verlag.

Molz, F. J., and G. K. Boman. 1993. A fractal-based stochastic interpolation scheme in subsurface hydrology. *Water Resources Research* 29.

Muller, J., J. P. Hansen, A. T. Skjeltorp, and J. McCauley. 1990. Multifractal phenomena in porous rocks. *Materials Research Society Symp. Proc*. 176:719-722.

Palmer, M. W. 1988. Fractal geometry: A tool for describing spatial patterns of plant communities. *Vegetation* 75:91-102.

Prettyman, D. H. 1992. Forest Soils-Climate-Site Index Relationships for Minnesota, University of Minnesota, Minnesota Agricultural Experiment Station, Minnesota Report 228-1922.

Prettyman, D. H. 1994. Generic Sampling System for Biophysical Data. Natural Resource Services, Ltd., NRSL PUB. 1-94.

Prettyman, D. H. 1998. Itasca County Land Department Biophysical System Project Manual, Natural Resource Services, Ltd.

Rex, K. D., and G. P. Malanson. 1990. The fractal shape of riparian forest patches. *Landscape Ecology* 4:249-258.

Tisdale, S. L., and W. L. Nelson. 1966. *Soil Fertility and Fertilizers*. 2d ed. New York, NY: The Macmillan Co.

Trauger, D. L., and R. J. Hall. 1992. The challenge of biological diversity: Professional responsibilities, capabilities, and reality. *Trans. N. Am. Wildl. And Nat. Resour. Conf.* 57:20-36.

Tyler, S. W., and S. W. Wheatcraft. 1990. Fractal processes in soil water retention. *Water Resources Research* 26:1047-1054.

Van Arsdel, E. P. 1965. Relationship between Night Breezes and Blister Rust Spread on Lake States White Pines. USDA, Forest Service. Res. Note LS-60.

Warner, W. S., and G. Fry. 1990. Evaluating small-format photogrammetry for forest and wildlife surveys: Euclidean vs. fractal geometry. *Forest Ecology and Management* 31:101-108.

Wilde, S. A., J. G. Iyer, Ch. Tanzer, W. L. Trautmann, and K. G. Watterson. 1965. Growth of Wisconsin coniferous Plantations in Relation to Soils. Res. Bull. 262. Madison, WI: University of Wisconsin.

Red Pine Regeneration

Dan Farnsworth[1]
Michigan Department of Natural Resources (retired)

ABSTRACT. Techniques to achieve consistent natural regeneration of red pine on most sites have not been developed and used. A few specific habitat types regenerate naturally without special silvicultural site prep. Timing of site preparation to seed year is important for natural regeneration. Fire, chemical, mechanical or a combination is needed to naturally regenerate most sites to red pine. Artificial regeneration is the most widely used and reliable regeneration method with present technology. Initial planting rates below 700 trees per acre will result in stands producing primarily pulpwood and lower quality sawlogs. Contracts for stock and planting should have measurable items and be measured for quality control. Bare root, containerized, and peat pots all provide good planting stock. Bare root stock does best with a refrigerated delivery system, survive and grow best when machine planted. Containerized and peat pots are the best hand planting choice but may need a field watering system. Peat pots create severe handling problems when root growth joins pots together. The timber sale influences the amount and difficulty of site prep needed for regeneration. Fire, chemical and mechanical site prep can be used interchangeably or in combination to create a free to grow stand. A "GIS" based data tracking program will define the stand status and need for release, or insect and disease problems. Velpar® is the most reliable release technique.

KEY WORDS: Red Pine Regeneration.

Regeneration Program Administrative Concepts

Planning and administration is essential to have a successful red pine regeneration program that creates red pine stands that are free to grow. The resources available, guidelines and policies of the organization will dictate the methods used to regenerate red pine stands. Prior to regenerating red pine, decisions need to be made concerning whether artificial or natural means will be used. Will the labor force be "in-house" or contracted? Does the timber sale cutting specifications facilitate regeneration after harvest. Is there a regeneration tracking mechanism in place to monitor the success or problems needing correction as the stand develops.

[1] Farnsworth, D. 2002. Red pine regeneration. In *Proceedings of the Red Pine SAF Region V Technical Conference*, eds., Gilmore, D. W., and L. S. Yount, 44-53. Staff Paper no. 157. St. Paul, MN: University of Minnesota, College of Natural Resources, Department of Forest Resources

Regeneration Tracking Program

A regeneration program needs a method to track the components and the progress of the regeneration. The ideal tracking program should be "GIS" based such as the one developed for the Michigan state forest system by Thomas Moen. Detailed site maps prepared with a GPS unit are stored in a GIS database. This base catalogs the site location by compartment and stand, and site preparation treatments. It records planting information as to date, number of seedlings, origination of seedlings, planting contractor, and type of planting. Plantation progress is recorded from measured plot data. This data is even more essential if the stand is being regenerated naturally. The regeneration program should generate the data necessary to prepare a budget request for acres to be site prepared, planted, released, conduct insect and disease monitoring and control.

Sampling techniques for the regeneration program need to be standardized for the unit. Samples can be plots for accurate tree number and survival data or eyeball observations for insect and disease problems. Sampling for release needs can be accurately done by either method. Plots can be line plots, or fixed area plots ranging in size from 1/1000 to 1/10 acre in size. It is essential to plot sample at the end of the first and second growing seasons for survival and release needs. If survival is poor, the stand can be replanted before all the site preparation benefits are lost. Plot sampling for tree numbers, growth. competition, insect and disease is recommended in year 4 and 6 to identify problems and prevent them from developing into major untreatable conditions that reduce the quality of stand. Ocular sampling every other year from age 7-15 for competition, insects and disease will identify and schedule treatments if problems are developing in the stand.

Labor Source—In-house or Contracted

Very few organizations have enough employees to accomplish a substantial regeneration program; some portion of the program will be contracted. The following ideas are a useful checklist to use in contracting. All contracts should be quantitatively verifiable with penalties for improper fulfillment of the contract. For example, "Plant all trees 6 feet apart in trenches, a 10% penalty will be deducted if the spacing between seedlings is less than 5'6" or greater than 6'6".

Stock purchase needs to be specific as to type and size. Containerized stock for hand planting should be 7-12 cm in size. Visit the nursery growing the stock, bring a ruler and randomly sample the stock and then only pay for the seedlings in the contracted size range. Bare root stock should be treated similarly.

Site preparation contractors should have the equipment to do the contracted job in the desired time period. Spacing between rows or planting sites should be defined in the contract. Make sure that the site can be prepared for planting. Is it to rocky, stumps to high or impossible to access? Allow sufficient time for the site prep to be done in advance of planting. I was occasionally guilty of this. The skidder and trencher never did run over a hand planter, but it was close.

Planting contractors should have a proven performance record. A multiple season and year contract is often beneficial to you and the contractor. It does require advance planning to keep the contractor informed as to the size of the planting program so he can hire the planters and fit you in his schedule. Bid the planting out early. If your purchasing department is slow get the information for the spring planting to them in December. It is not nice to be wondering who will get the planting bid on May 1. Write the contract so that the whole or a portion of the contract can be rapidly reassigned to another contractor in case the successful bidder is not capable of completing the task on time.

Chemical application contractor must have all the necessary certification, licensing, and insurance. These are the contractors of greatest concern because of the potential environmental and legal problems. It is very useful to have a staff person who is a certified pesticide applicator and very knowledgeable in the use of pesticides oversee this contract.

Contract for Professional assistance during planting season or to do plantation monitoring. Do not forget your self. In governmental organizations planting and fire season overlap. On fire days there will be no help to monitor the crews or deliver trees. You can not do the entire job your self especially if you have two hand crews and three machine crews spread across 150 miles of forest.

Timber Sales and Reforestation

Most red pine regeneration takes place on cut-over sites. This is a much more complicated task than planting an open area with no stumps. The timber sale should contain specifications to enhance not hinder regeneration efforts. For sites to be regenerated naturally, specification for low stumps, good utilization, and cutting during the snow free season and removal of slash are important. For artificially regenerated sites stumps, should be no higher than 6", slash scattered not tight dense large piles, and access roads driveable. If the site is to be burned after harvest, the timber removal roads should be located to serve as fire breaks. The most important specification on any timber sale to be reforested after harvest is to have a specification that stump height shall be no greater than 6". A chipped whole tree harvested site is one of the easiest sites to work.

Natural Regeneration

Natural Regeneration of red pine is a technique that the forestry profession has not mastered. Certain sites regenerate to red pine regardless of what is done. On the other 90% of sites, natural regeneration is a hit and miss proposition with out tested techniques for success. Part of the problem is that red pine planting guarantees a stand. Managers have been reluctant to use natural regeneration unless forced by political decisions. Another factor is that red pine stands currently under management are immature and not in need of regeneration. This is changing. Many red pine stands are now 100-120 years old. This is the average age at which red pine stands regenerated prior to fire control and commercial harvest. Additional field trials and research is needed to develop techniques that work most of the time. The variables in natural red pine regeneration is a seed source, mineral soil seed bed and space to grow after the seed germinates.

Seed Source

The stand needs to be prepared for regeneration by a timber sale. The seed tree stocking can be variable ranging from 25-75% crown cover. It is important that the seed trees have large well-developed crowns. Red pine seed crops occur at variable intervals averaging about seven years. Good seed crops can be local or regional in nature. Stand to be regenerated should be checked at regular intervals to determine if the seed crop is sufficient to warrant site preparation that exposes a mineral soil seed bed. By checking the stands across a broad area localized seed crops will be found. This provides opportunities to utilize regeneration resources in more than the one in seven years on which regional seed crops occur.

Site Preparation

Fire is Nature's site prep tool. Cool fires maintained the stand and a hot summer fire that exposed mineral soil was the site preparation required to regenerate the stand. One of the most critical tools needed in natural red pine management is the use of fire in stand management. The big drawback to prescribed fire is that it is a political football and not always available when the seed year is right.

Mechanical site preparation is a more reliable source of mineral soil exposure. It is available when the seed source is ready without any constraints except budget monies. Mechanical site prep needs to expose mineral soil. Thousands of acres of cut over stands were successfully chain drag scarified for jack pine regeneration in the Eastern UP. Often a red pine seed source was available but very few red pine seedlings resulted from chain drag scarification. It did not expose enough mineral soil. Site preparation techniques such as trenching, disking that expose more mineral soil may work better.

Chemical site preparation used in combination with fire and/or mechanical methods may assist in reducing vegetative competition after the seeds germinate and reduce vegetation to allow mechanical equipment to work more efficiently.

Naturally regenerated stands will need to be monitored to determine if it has regenerated. Successfully regenerated stands will be variable in tree numbers and distribution. 400-700+ well-distributed seedlings are a very successful effort. The regeneration tracking program will document when the stand is regenerated

Overstory removal is necessary to allow the young seedlings to develop and to prevent disease problems. Disease problems due to deerskin droop (*sirociccus*) and Diploda (*Sphaeropsis sapinea*) are much greater when the overstory is left in place. The overstory should be removed when seedlings are small to prevent seedling damage during harvest. The overstory can be removed in two separate harvests, but this will increase the probability of seedling damage during harvest.

Field trial plans to test a variety of techniques to naturally regenerate red pine are in place on state forest land in the Eastern Upper Peninsula. A 1937 CCC plantation will serve as the test site. The trees range from 14"-20" DBH. The trees are large crowned with crown closure ranging from 25-100%. Site Index is 65. Sand roads divide the area into three portions. The test is to burn the entire site and then time the following treatments to a good seed year:

- burn
- herbicide and burn
- mechanical and burn
- burn, herbicide and mechanical
- herbicide and mechanical
- mechanical
- herbicide
- control

This test has not been completed at the present time. Several other stands have been scheduled for understory burns in good seed years. Hopefully these tests will increase the knowledge for techniques to naturally regenerate red pine. There are several excellent examples of understory burns regenerating red pine on USDA-FS lands in the Eastern Upper Peninsula.

Artificial Regeneration

Artificial regeneration has been the most common method to create red pine stands. There are many reasons to use planting instead of natural regeneration. Many red pine plantings were old field or areas deforested by harvest and fires. The uniform distribution of the trees produced high volume yields. Planting is reliable. All the stumpage value of the existing stand was realized. Insect and disease problems are reduced. The stand being regenerated to red pine lacked a red pine seed source. It is easier to plant the stand than regenerate it naturally; we are all geared up to plant. Many decisions need to be made in establishing a red pine plantation including what type of stock, how will the stock be handled, what site preparation is necessary for this area, hand or machine planting.

Planting Season

Spring planting season has historically been the favored planting season with slightly better plantation survival, especially with machine plants and bare root stock. With a large planting program all the work cannot be jammed into the spring season so a fall season may be necessary.

Fall planting with containerized stock has given the most consistent and successful plantations on state forest land in the Eastern UP. By planting in September the seedlings established roots deep into the soil and were not affected by spring and summer dry spells in the year following planting. We never had a plantation failure or replant of a fall planting using containerized stock.

Planting Stock

Is the choice of stock an option in your regeneration program? Often this choice is predetermined because the organization owns a nursery producing bare rootstock or a greenhouse growing styroblock containerized seedlings providing the stock for all planting operations. If this choice is made for you then you need to design your program to efficiently use the stock provided to you.

Bare Root stock is still the most common type of planting stock in regenerating red pine. It is readily available, usually is lower cost, and works well in planting machines. Bare rootstock needs to be kept cool and moist during storage, delivery, and planting. A refrigerated storage and delivery system improves the stock quality at the planting sites. This improves the survival of the planting. A small refrigerated trailer towed by a pick up delivers and stores stock at the planting site in excellent condition. These small units can negotiate all types of forest roads and are not affected by road restrictions. If refrigeration at the site is not an option seedling protection tarps covering planting stock in the shade are the second best option. In the Upper Peninsula placing the stock bags in a snow bank under a coniferous tree and covering them with a protective tarp is an option. There are many examples of machine planted bare root stock surviving and growing better than hand planting. Hot dry days are deadly on bare root stock. If a root dip is used to prevent root drying the slurry should be very watery. There is mixed evidence as to the value of root dips. At least one study has shown lower survival with a root dip.

Containerized stock in styroblocks is becoming increasingly available. Containerized stock is easily shipped for short distances and can be stored on the site without refrigeration. If stock is delivered to the site more than two days prior to planting it may have to be watered. The best planting method is to plant the trees directly from the styroblock, by attaching it to the planter with a clip. The trees can also be pulled from the block and put in a planting bag. This does destroy some of the plugs especially if the plugs are very dry. Do not plant dry plugs. Containerized seedlings can be machine planted but it is difficult. They are best suited for hand planting. The biggest drawback to styroblock containerized seedlings, especially if purchased under contract, is returning the blocks to the nursery. If syroblock seedlings are purchased with a contract put the cost of block return into the contract. This is also true of peat pot containers.

Peat pots are another type of containerized seedling that is currently available for planting stock. The company selling the pots has a lot of their research that shows peat pots grow and survive better than other type of seedlings. They work very well if your greenhouse and planting program is small. However, if you are conducting a large planting operation that spans many weeks, stock handling and care create severe problems. The stock from peat pots was typically smaller than styroblock stock. There were a higher percentage of trees less than the contract specification of 7 cm. This is probably due to the reluctance of the nursery to grow them larger and let the roots join all the pots together in a mat. The tendency of the roots to join all the pots together in a tightly bound mat creates severe handling problems in the field. A substantial percentage of the seedlings are destroyed tearing them apart even after they have been cut in one direction. The separating of the plants slowed the planting rate considerably. If the contractor knows they will be dealing with peat pots the costs will be higher. After several frustrating years of administering a large fall planting program with peat pots myself and another Michigan DNR employee declared to the purchasing agent, “no more peat pots.”

Site Preparation

Site preparation is critical to the growth and survival of the planting. Site preparation can involve fire, mechanical, and chemical methods or no site prep with possibly a chemical release after planting.

Fire is an important site preparation tool to reduce competition and remove slash loads allowing equipment and chemicals to work more effectively. The majority of the red pine regeneration done on state land in the Eastern Upper Peninsula of Michigan (UP) was reforesting of clearcut CCC 1930s plantations. The slash loads were very heavy and an impediment to the effectiveness of mechanical site preparation, with a TTS trencher, and chemical site prep by slowing or altering spray patterns and by preventing the spray from reaching the target. Several sales were sampled for untreatable areas without a fire. The results showed that 25% of the area would not be planted. Fire will also substitute for chemical site preparation. Broadcast burns generally cost $40-100 per acre.

Some form of mechanical site prep greatly improves survival and ease of planting a site. Mechanical site preparation is most commonly done with a machine that removes the sod or duff layer. The TTS trencher, Bracke patch scarifier and V-Plow on the planting machine all do a good job of site preparation. Hand planting is much easier when a site is prepared. When a TTS Trencher is used it provides travel lanes for the planters and organizes the site decreasing planting skips. Contract TTS Trencher costs are $40-$50 per acre. Approximately 10-15 plantations without mechanical trenching were tried over a 20-year period on state forest land in the Eastern UP of Michigan. These efforts yielded very mixed results and more failures than successes. Trees were planted in natural and prescribed fires, and areas prepared with a chain drag scarifier. Half failed and half succeeded. Old sand and gravel borrow pits usually produced a plantation. Sites planted with no trenching and follow up release always failed. The plantations that were chemically released after planting succeeded while the unreleased plantations failed.

Chemical site preparation provides an excellent growing condition for newly planted seedlings. When the chemical labels are followed, a variety of chemicals provide excellent herbaceous and woody competition controls. Velpar®, Accord® (glyphosate), Arsenal®, Garlon®, Oust®, Tordon®, all have site preparation labels. Often the cost and effectiveness of site preparation is improved by using a combination such as glyphosate-Oust®. Glyphosate, Garlon-4®, Oust®, and Velpar® can be applied during the same growing season as the planting. The other chemicals usually need to have a longer period of time between chemical application and planting to allow the chemicals to break down and not harm the red pine. One of the most effective treatments we tried was a home made sprayer on a planting machine that applied Velpar® in front of the planting shoe. Wick applicators of glyphosate also work. Just as long as the chemical does not come in contact with the seedling. How to apply the chemical is always an expensive question. Home made or adapted agricultural sprayers have many drawbacks and complications. Spot hand application may work in certain instances for herbaceous weed control on small plantations. This is especially true for small private land owners. Planting spots created with a spot spray of Velpar® immediately after the ground thaws in the spring will be visible brown patches when the site is planted just after the remaining vegetation becomes green. A large skidder mounted computerized sprayer works well. Fixed wing aircraft also work. However, for large site prep programs the first method of choice is application with a helicopter.

Tree Planting Method –Machine or Hand

The choice to use a machine or to hand plant red pine depends primarily upon the ruggedness of the site and to a lesser degree the type of stock available.

Machine planting is best done on sites with without concentrations of rocks and solid stumps. Machines do an excellent job of planting old agricultural fields, grass openings, replants of failed plantations with existing scattered regeneration, or sites harvested 5-6 years prior to planting. Stumps on harvested sites need to be as short as possible and preferably less than 4” in height. The use of the processor ended the quick follow-up machine planting of harvested sites in the Eastern UP state forest. The large stumps were always too high to machine plant. To machine plant harvested sites the stumps either need to be spaced at least 20 feet apart or have decayed to the point that the equipment crushes them. High concentrations of football and larger sized rocks are guaranteed to break the planting machine and result in a plantation with poor tree distribution and survival. Machine planting and furrowing with a plow on the tractor or planter, or chemical band treatment while planting provides a one passes operation of site prep and planting that is cost effective. Costs of machine planting cost from $60.00 -$70.00 per acre for old fields. Cost increase to $100-110 /a. to plant easy harvested sites. Containerized seedling are not well suited for a planting machine. A machine plant including chemicals and application will cost $140.00-$150 per acre.

Hand planting is best suited for the sites with hard stumps, rocks or wet spring access. Contract crews are readily available and usually supply a high quality planting at a low cost. Containerized seedlings make the best hand planting stock. Cost of hand planting is $40.00-$50.00 per acre. Mechanical site prep is usually essential to achieve a good hand planted plantation.

When comparing costs of Hand planting versus Machine planting the cost of either method is almost the same. When the cost of trenching and higher supervision cost are combined for hand planting they may only be a few dollars more or less than machine planting a site. The choice of planting method is not economic but related to the following questions: Can the site be machine planted? What type of stock is available? Will site prep for hand planting destroy most of the existing regeneration? What planting contractors are available? Will the Immigration Service visit the site and leave you without a crew?

Release

The tending of a planting or naturally regenerated stand in the first 10 years is critical to the establishment of a red pine stand. Stands do not have to be pure red pine but red pine should comprise most of the trees in the stand. In more intensively managed stands 85-95% of the red pine should be free to grow at age 10, extensively managed stands may only require 50+ percent of the trees free to grow. Many red pine planted from 1930 to 1980 on state forest land in the Eastern UP did not become red pine stands because they were killed by herbaceous competition in the first three years, or finally succumbed to overtopping woody competition 10-20 years after planting. A chainsaw release at age 20 does preserve some trees, but the growth is lost and the tree quality is generally lower. Implementing a stand tracking program is essential to determine if the stand needs release and how it should be released.

Stands need to be released prior to the competition slowing the growth or potentially killing the tree. There is no need to release dead red pine. As a rule of thumb vegetative competition will kill the tree in 2-4 years after planting while red pine may linger under woody vegetation for many years, especially if it is low shade species such as aspen, birch, or cherry. The release from herbaceous vegetation needs to be done promptly while release from woody plants can be delayed 1-2 years after a problem is detected. Some growth will be lost for every year the release is delayed. Herbaceous competition needs to be eliminated when less than 40 to 50% of a 2-foot circle at the base of the seedling is mineral soil. If you cannot see bare ground at the base of a 1-2 year-old seedling that tree has a high probability of dying. If the competing weeds are tall grasses or ferns that totally overtop the trees, the site needs a release. Releases for vegetative competition do not have to be a total site release. If it is a practical band or spot, releases with Velpar® will give the seedlings the 1-2 years that they need to outgrow herbaceous competition. Good site preparation should eliminate the need for release from herbaceous competition. The only practical method I am aware of for release of red pine from herbaceous competition is to use chemicals such as Velpar®, which is very safe, or a fall application of glyphosate after the seedlings have been in the *ground two years, and the late summer was not warm, wet and humid*. The stand needs release if more than 10-20% of the red pine crowns will be growing underneath the canopy of a tree that is considered undesirable competition by age 30. The small competing trees need to be more than 40-50 feet apart to have 80-90% of the red pine free to grow at age 30.

Chemical release is the easiest and surest method of release. Velpar® is the most common release chemical. It does not harm the red pine seedlings when applied directly over the top of them. It can be applied from the air or ground as a broadcast spray, or spot application with hand equipment. The hand gun spot application of pure Velpar® is very effective on clumps of clonal species such as aspen and it only treats those areas that need release. The other chemical often used for release is a fall application of glyphosate. Glyphosate is much more difficult to apply so that no damage is done to the red pine. Use the rate recommended on the label at the lowest level possible. The trees must be planted at least two years. The weeks prior to the application should not be warm, rainy and humid. It must be applied after September 1 but prior to the first frost to be effective on woody competition. Often the cherry have lost their leaves and are not killed. If you talk to most foresters who have done a substantial amount of release with glyphosate, you will find that a few stands have been replanted after the release served as a total site prep removing the red pine along with the competing vegetation A chemical release with Velpar® generally costs $75-90.00 per acre.

Hand release of red pine can be done when the competition is woody vegetation. This can be accomplished by severing the stems of competing woody plants or chemically releasing them with Garlon-4® or Velpar®. The mechanical release works best when the pine are 6+ feet tall and the competing trees cannot out grow and overtop the pine at sometime in the future. Another method that works well should be timed to coincide with the first time you can pick enough blueberries for a pie. Partially severe the stems of the competing trees or shrubs leaving a narrow band of cambium intact. Tip the stem so that the top touches the ground but the cambium strip is still in place. This system not only takes the shade off the top of the pine but it also kills the competing tree by starving it. Trees killed in this manner with proper season timing do not sprout back.

My Regeneration Choice

If I had my choice after 32 years of state employment, how would I prefer to regenerate a red pine stand? An interesting question. If I had a seed source available, and not being afraid to fail occasionally I would like to do it with fire with a little help from mechanical site prep and a chemical release if needed. If I was going to plant a cut-over site I would site prepare it with a early summer application of glyphosate-Garlon-4®, burn it in August, trench immediately after the burn and plant styroblock containerized seedlings the first week of September. If I was asked to reforest an old field, I would machine plant it in the spring, with a band application of Velpar® as a 1-shot planting, furrowing, chemical site prep operation.

An Ecological Context for Regenerating Multi-cohort, Mixed-species Red Pine Forests

Brian J. Palik and John C. Zasada[1]
Research Ecologist and Research Silviculturist, respectively,
USDA Forest Service, North Central Research Station, Grand Rapids, MN.
Phone: 218-326-7100; bpalik@fs.fed.us; jzasada@fs.fed.us.

ABSTRACT: Human disturbances have simplified the structure and composition of red pine forests, relative to historical conditions. A greater understanding of natural disturbances and their role in generating complex stand structures, and their associated benefits, has increased interest in managing for mixed-species, multi-aged stands. A useful framework for addressing issues of structural and compositional complexity in management is a conceptual model that arrays stands along axes of silvicultural actions, time since disturbance, and degree of complexity. We use this model to assess degree of structural and compositional disparity between benchmark and managed conditions. In practice, we are using overstory retention to add age and compositional complexity to red pine stands. We are managing for two-cohort structure and, potentially, multi-cohort structure. We are adding compositional complexity through planting and natural regeneration of multiple species. Moreover, we are experimentally altering spatial patterns of retention to favor regeneration of species differing in understory tolerance.

KEY WORDS: red pine, mixed-species silviculture, multi-cohort structure, overstory retention

---

Introduction

In many parts of the Great Lakes region, commercially managed red pine forests differ greatly in structure and composition from historical conditions. Many stands were regenerated artificially in even-aged plantations. In other instances, red pine regenerated naturally, after initial logging, on sites it occupied historically. However, even in these cases, structure and composition differ from the historical condition: for instance, single-cohort versus multi-cohort age structure and monospecific versus mixed-species composition. Still, these simplified stands are important biological templates that are closer to the historical condition of red pine growing on "red pine sites" than, for example, are white spruce plantations on northern hardwood sites.

---

[1] Palik, B. J., and J. C. Zasada. 2002. An ecological context for regenerating multi-cohort, mixed-species red pine forests. In *Proceedings of the Red Pine SAF Region V Technical Conference*, eds., Gilmore, D. W., and L. S. Yount, 54-64. Staff Paper no. 157. St. Paul, MN: University of Minnesota, College of Natural Resources, Department of Forest Resources.

Where such stands exist, they provide opportunities to test silvicultural approaches for increasing structural and compositional complexity in managed forests. Here we discuss why adding structural and compositional complexity is an important consideration in forest management. We briefly examine red pine forests from an historical perspective, asking whether stands were more complex naturally. We examine the extent to which red pine management in the contemporary landscape incorporates complexity. Finally, we outline a conceptual approach for adding structural and compositional complexity into commercial red pine management and we illustrate application of the approach in an operational–scale management experiment.

A Landscape Perspective on Forest Management

It is important to frame our discussion of multi-species and multi-cohort red pine forests within the appropriate landscape perspective (Figure 1). This perspective, derived from the "triad model" (Hunter and Calhoun 1996), allocates the landscape into three distinct uses. These include intensive management, where fiber production is the top priority, reserve management, where sustainability of native biological diversity is the priority, and extensive management, where commodity production and sustainability of biological diversity are shared priorities, although the balance between the two will shift depending on the specific circumstances.

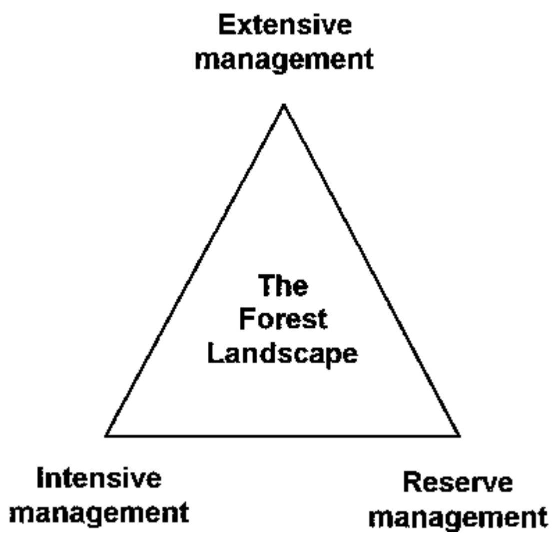


Figure 1. A conceptual zonation of the forest landscape based on tradeoffs between timber production and sustainability of biological complexity and diversity. Adapted from Hunter and Calhoun (1996).

Management for mixed-species forests and multi-age cohorts can certainly be an issue in ecological reserves, since for many forest-types this is, or was, a condition often found in the unmanaged, or natural system. In contrast, intensive management generally focuses on sustainability of fiber growth and yield, with only minor consideration given to other ecosystem goods and services. We argue that the greatest need for more consideration of complexity falls within the area of extensive management, where timber production is balanced against sustainability of a broad range of ecosystem goods and services, including biological diversity. It is within the realm of extensive management that our discussion is best considered.

Why Manage for Multiple Species and Multiple Age Cohorts?

The answer to the question, W*hy manage for multiple species and multiple age cohorts*, reflects an evolving understanding of the forest stand. Traditionally, the stand as a silvicultural management unit embodied ideas of homogeneity and simplification of structure and composition within stands, and similarity among stands in the landscape. In practice, many management practices, overtly or inadvertently, lead to simplification of structure and composition and reduced variation in characteristics within and among stands.

More recently, there is increased interest in redefining stands to be more inclusive of heterogeneity and complexity of structure and composition (Franklin et al. 1997), as well as greater variation of characteristics among stands in the landscape. This interest stems largely from studies of structure and composition in natural forests and how such forests develop after natural disturbance. These studies point to the importance of biological legacies, that is, elements of forests such as residual trees, understory plants, dead wood, mycorrhizal fungi, etc., that survive disturbance and add complexity to the post-disturbance stand (Franklin et al. 1997). An important conclusion of this line of research is that most forest ecosystems, at all ages or stages of stand development, are naturally more complex then their managed counterparts. This complexity typically includes multiple age-cohorts and mixtures of overstory tree species.

An outgrowth of natural disturbance research is the premise that silviculture should be modeled after natural disturbance regimes and, more to the point, the structural and compositional outcomes of silviculture should reflect the outcomes of natural disturbance (Franklin et al. 1997; Palik et al. 2002a). The rationale behind this premise is that the ability to maintain genetic structure, species communities, and ecological processes in managed forests may reflect the degree that silviculture creates the same complexity and variety of structures and composition as natural disturbances.

The Benefits of Complexity

It is not sufficient to say that nature's way is the right way, as a justification for modeling silviculture after natural disturbance and adding complexity to managed forests. There must be demonstratable benefits. We believe that there are, although admittedly, some of these benefits are best considered working hypotheses. For instance, productivity of mixed-species forests may be greater than monospecific stands of the individual species (Kelty 1992). The hypothesized mechanism behind this effect is that diverse forests may be better at utilizing available resources if the component species complement each other in resource capturing capabilities. Moreover, diverse forests may be better able to recover from disturbance, i.e., they are resilient, because of differential susceptibility of component species to the disturbing agent. This has important implications for forest health in that mixed-species forests may be less susceptible to pathogen or insect disturbance than are monospecific forests of susceptible species. Structurally and compositionally complex forests provide a diversity of habitats for associated plant, animal, and microbe species and communities. As such, within stand diversity, or alpha diversity, of native species should be higher in complex forests than in their simplified counterparts.

Structurally and compositionally complex forests provide opportunities for pursuing diverse management objectives. Complex forests contain a greater diversity of marketable products, including multiple timber species, multiple timber products (e.g., sawlogs, veneer, pulp), and multiple nontimber products (e.g., bark, berries, roots, medicinal herbs, mushrooms, etc.). Structural and compositional complexity leads to greater within-stand and landscape-scale diversity of wildlife habitat (e.g., living and dead snags, vertical canopy structure) and greater recreational appeal. Heterogeneous growth environments in forests with complex age structure often result in periods of suppression and release, at least for some trees. This can result in higher wood density and narrow growth rings, which for some species and timber products can lead to higher quality and higher valued wood. Finally, compositionally diverse forests allow greater flexibility to pursue alternative management objectives, for instance, by altering successional pathways to favor different species if and when management objectives change.

Were Red Pine Forests Complex Naturally and Are They Now?

By most accounts, natural red pine ecosystems are more complex, compositionally and structurally, compared to their managed counterparts. Some evidence for this comes from examination of bearing tree data in General Land Office survey notes. Several studies from different areas in the northern Lake States suggest that on sites typical for red pine, a variety of other species had greater cumulative abundance in the overstory than did red pine (Figure 2). In contrast, contemporary inventory data for the same region (Miles et al. 1991; Leatherberry and Spencer 1994; Schmidt 1997) suggest that other species in the red pine type now contribute only 20 to 40% of total volume (Figure 3). Similarly, age structures of old-growth and mature red pine forests were more complex than contemporary managed stands. For instance, the age range of red pine in an old-growth stand in northeastern Minnesota approached two hundred years (Heinselman 1973). The age range for the stand approached three hundred years when additional species were considered. In contrast, most mature red pine stands in the Lake States are single-cohort stands planted in the 1930s and 1940s. Even in the best examples of naturally regenerated, managed red pine stands, age structures are likely to be less complex and less variable than the natural system. For instance, with the exception of scattered old individuals, red pine in mature stands on the Chippewa National Forest, Minnesota, fall within a 40-year age range when aged at breast height, and probably a narrower range when actual ages are considered (Figure 4).

When considering the importance of complexity of structure and composition in natural forests, it is important to recognize the role of natural disturbance in generating variation in structure and composition (Landres et al. 1999). In the presettlement landscape, not all red

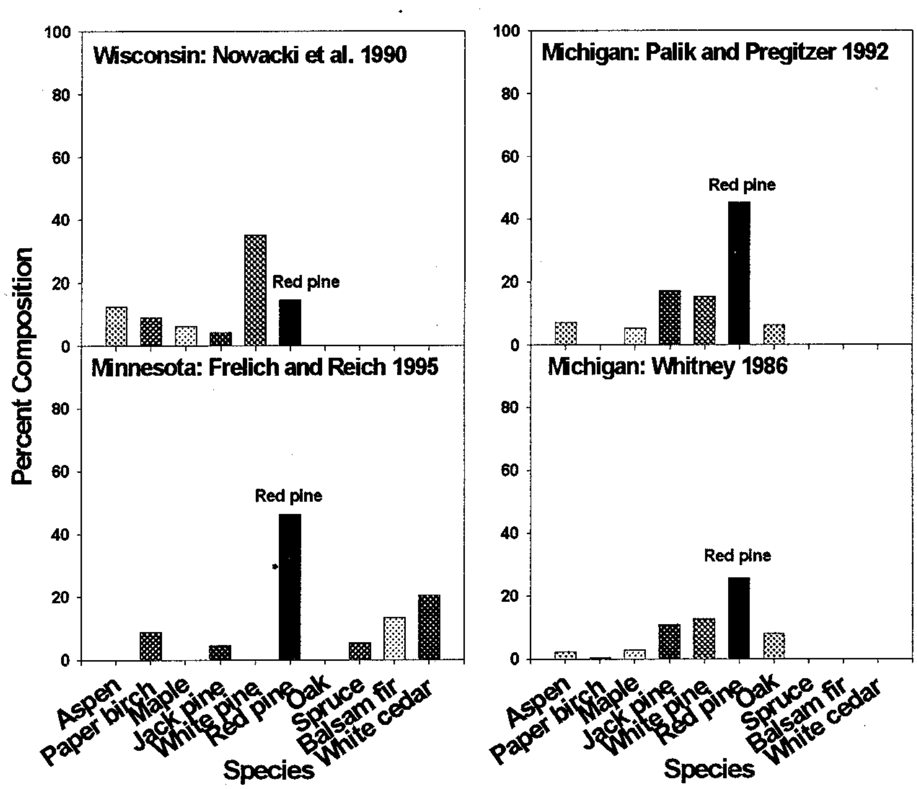


Figure 2. Species composition of bearing trees in presettlement pine forests in the northern Lakes States.

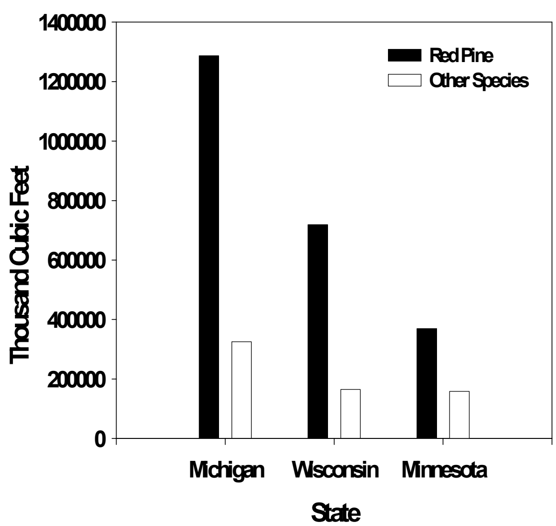


Figure 3. Volume of red pine and other species in the contemporary red pine forest type in the northern Lakes States.

pine forests likely were as structurally and compositionally complex as the examples we give. As such, single-cohort age structures and dominance of a single species, as are common for contemporary red pine stands, may well fall within the range of natural variation for the system. However, potential problems exist when simplified systems dominate the managed landscape, such that the range of variability in structure and compositional complexity is greatly reduced, as in the contemporary landscape, relative to the conditions generated by natural disturbance.

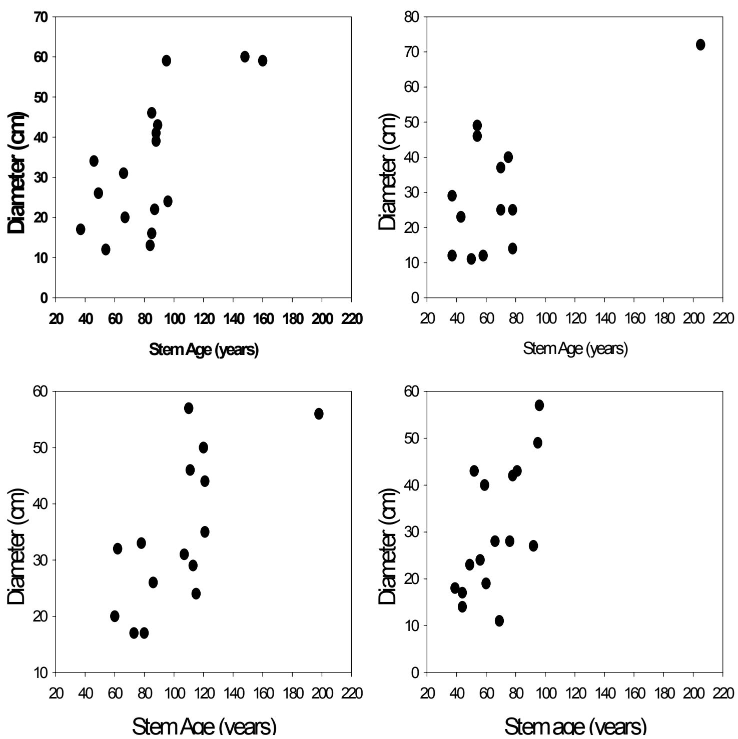


Figure 4. Age structure of four naturally established red pine stands on the Chippewa National Forest, Minnesota (John Zasada, unpublished data).

Adding Complexity into Managed Red Pine Forests

A Conceptual Model

A useful framework for addressing issues of structural and compositional complexity in management is a conceptual model that portrays an array of stands along a gradient of management intensity and desired future conditions (Figure 5). On the right end of the gradient is the unmanaged, benchmark condition, characterized by diverse composition and structural complexity. This may be the condition of choice if management of ecological reserves is the primary objective. On the left end of the gradient is the intensively-managed condition. An extreme example is a short-rotation, single-cohort plantation of an exotic species, where maximization of fiber production is the objective. There is a wide array of conditions between the endpoints, falling within the region of the model we call extensive management. These conditions could include extended rotation, single-cohort red pine plantations and multi-aged, mixed-species stands managed with overstory retention. It is important to consider the differences and disparities between intensively managed stands and ecological benchmarks for two reasons. First, it is important to determine the size of the disparity between the benchmark and managed conditions and take steps to reduce the disparity, if that is a management goal or desired future condition. It is equally important to understand the size of the disparity from the intensively-manged end of the gradient. In other words, it is important to understand not only how far management has to go to reduce disparity with the benchmark condition, but also to judge success in adding complexity to stand structure and composition.

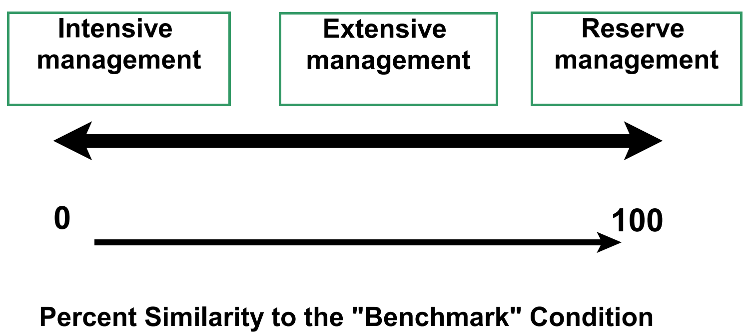


Figure 5. Linear conceptual model for evaluating the degree of disparity in compositional and structural complexity between managed red pine systems and the benchmark condition.

This conceptual approach for considering management outcomes is more instructive when dimensions of time and spatial variability of complexity are added to the model (Figure 6). In this expanded model, the area in gray represents the domain of natural variability of the system, as defined by combinations of time since disturbance and degree of complexity of age structure and composition. Thus, the gray area represents the array of benchmark conditions for the system. It is important to recognize that the domain of natural variability includes not only old-growth red pine systems, having varying degree of complexity, but also young post-natural disturbance systems. The point being that even immediately after a catastrophic natural disturbance, young stands do contain high levels of complexity of structure and composition.

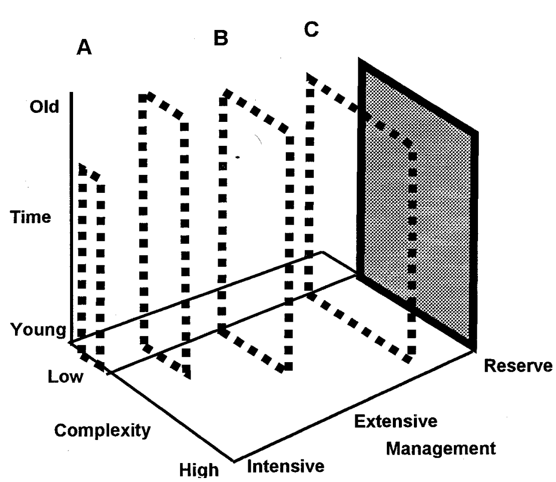


Figure 6. Multidimensional conceptual model for judging disparity in compositional and structural complexity between managed red pine systems and benchmark conditions. The area in gray represents the domain of natural variation in complexity of the benchmark condition, as a function of time since disturbance. The dashed rectangles represent domains of variability in complexity, as a function of time since disturbance, for a variety of management scenarios.

The dashed rectangles are domains of variability in age structure and composition for management scenarios differing in the degree to which they achieve multiple objectives, for instance wood production and sustainability of native species. Domain A might represent a plantation of an exotic species, established on a former red pine site, managed intensively for fiber production. Notice that range of variability in complexity is not only narrow, it is outside the range of natural variability. Domain B might include red pine systems managed for large diameter sawlogs and structural complexity by developing two-cohort stands. Notice the range of variability is narrow, relative to the benchmark condition, but still within the domain of natural variability. Domain C might represent systems managed for maximum similarity to a benchmark condition, for instance, with limited harvesting of naturally-killed trees.

In the model, we focus on outcomes of silvicultural actions and desired future conditions. However, the actions themselves can be overlain on the model. For instance, various activities, including site preparation, artificial and natural regeneration, and competition control, can be arrayed along the management axis depending on the extent to which and how the action is applied, e.g., more or less depending on intensity of management. This is important to consider because, ultimately, silvicultural actions influence the age structure and composition of the forest.

An important question for managers, when considering a gradient analysis like the one described, is to determine how close to the benchmark condition is close enough. The answer is objective driven. When managing ecological reserves, the goal probably will be to get as close to the benchmark condition as possible. When managing for maximum fiber yield, reducing the disparity with the benchmark condition is probably not a consideration. When managing for outcomes within the region of extensive management, reducing the disparity to the benchmark condition is an important consideration, but in many instances it will be done in ways that also consider constraints of meeting other objectives. With extensive management, the goal often will be to model the benchmark condition as close as possible, within the real-world constraints of managing for wood production. In this case, the objective is to shift stands to the right on the management axis (Figure 6) through innovative incorporation of complexity, while still maintaining timber production as a primary objective.

A Working Hypothesis

As a working example of our ideas, we are using overstory retention during regeneration harvests to add size, age, and compositional complexity to what are largely single-cohort, monotypic red pine stands (see Fig. 4), dominated by hazel in the understory. We are managing these stands initially for two-cohort structure and, potentially, for multi-cohort structure by retaining the residual overstory through a second rotation, along with a new cohort of planted trees. We are adding compositional complexity by planting eastern white pine, red pine, and jack pine. Overstory retention is combined with different levels of hazel control to provide better opportunities for tree recruitment and development of more species rich herbaceous and shrub layers.

While not as structurally complex as a multi-cohort benchmark condition for red pine ecosystems, our approach adds substantially more structural complexity to red pine stands than traditional single-cohort, single-species management approaches. Operationally, we are moving stands to the right on the management gradient (Figure 6), by restoring structural complexity, along with species and habitat diversity, to managed red pine stands, while still pursuing opportunities for sawtimber production.

In this project, we also are examining ways to manage takeoffs between restoration of biological complexity and growth and yield of timber species. Our approach tests different spatial distributions of overstory retention for their effects on resource availability and growth and survival of planted pine (Figure 7). In this research, overstory basal area is reduced to a similar low level in all treatments (e.g., ~ 60 ft^2/ac), but the spatial distribution of residual basal area differs from dispersed to small aggregate retention to large aggregate retention. We hypothesize, based on plant competition research in other pine systems (Palik et al. 1997, 2002b), that maximum resource availability and seedling growth of intolerant species at the whole stand-scale occurs with large aggregate retention, rather than dispersed or small aggregate retention, despite the fact that all three treatments have the same low residual basal area per unit area.

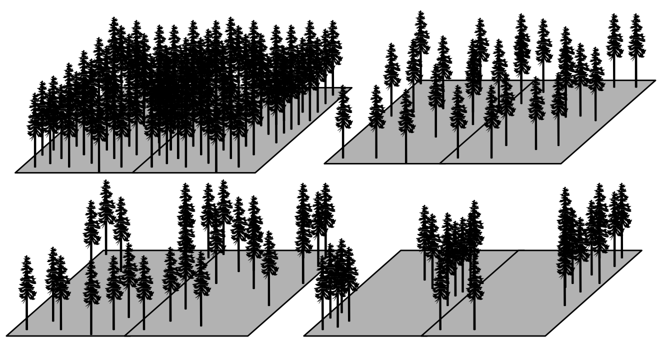


Figure 7. Conceptual representation of spatially variable overstory retention ranging from uncut forest (top left), to dispersed retention (top right), to small aggregate retention (lower left) to large aggregate retention (lower right). The three harvest treatments have the same amount of residual basal area.

Moreover, we hypothesize that by experimentally altering the spatial pattern of the residual overstory, from dispersed to large aggregates, we will alter the resource environment in the understory so as to favor different species with different retention treatments. For instance, assuming appropriate seedbed and forest floor conditions, eastern white pine may grow best with dispersed or small aggregate retention, whereas red pine and jack pine should grow best with large aggregate retention. Ultimately, our interest is in evaluating approaches for establishing mixed-species forests using variable retention (*sensu* Franklin et al. 1997), by incorporating dispersed and aggregate retention within the same stand to favor different species in different locations.

The primary goal of this research is to determine if we can minimize competitive inhibition of the new cohort of trees, relative to that which occurs under an intact overstory, while still adding structural complexity to the stand. However, we expect that spatial distribution of overstory red pine will influence other ecosystem characteristics, goods, and services (Table 1). For instance, the incidence of *Sirococcus* and *Diplodia* shoot blights in red pine seedlings, a concern when they are grown under a residual overstory, may vary with retention pattern. Similar to competitive inhibition of regeneration, we expect that the likelihood of *Sirococcus* and *Diplodia* infection will be minimized with large aggregate retention, because of greater spatial disassociation of overstory trees and seedlings. Abundance and production of competitive shrubs, as well as economically important nontimber plants, may also respond to retention pattern. For example, hazel and wild blueberries would likely have higher production with dispersed and aggregate retention, respectively, requiring more aggressive control for the former and providing more harvesting opportunities for the latter.

Table 1. Hypothesized effects of retention pattern on red pine ecosystem characteristics.

Characteristic	Dispersed	Aggregate
Regeneration growth (intolerant species)	Lower	Higher
Regeneration growth (tolerant species)	Higher	Lower
Hazel production	Higher	Lower
Blueberry production	Lower	Higher
Red pine needle blight	Higher	Lower
Logging efficiency	Lower	Higher
Residual tree damage	Higher	Lower
Campground quality	Lower	Higher
Fuels distribution	Uniform	Aggregated
Tree form and geometry	Uniform	Variable

Summary

We suggest the following points to consider when developing red pine management options:

1. Natural disturbance generates complexity in structure and composition of red pine systems, often, but not always, resulting in mixed-species, multi-cohort stands.

2. Great opportunities and need exists to incorporate increased complexity of structure and composition as a desired future condition for red pine management.

3. Overstory retention, to create two- or multi-cohort red pine stands, is a conceptually straightforward approach for increasing structural complexity while still managing for wood.

4. Variable retention, from dispersed to large aggregates, may favor species differing in understory tolerance.

5. Consider how spatial pattern of retention and different levels of complexity influence other ecosystem characteristics, including incidence of disease, understory shrubs, wildlife habitat, etc.

Literature Cited

Franklin, J. F., D. R. Berg, D. A. Thornburgh, and J. C. Tappeiner. 1997. Alternative silvicultural approaches to timber harvesting: Variable retention harvest systems. In *Creating a forestry for the 21st century*, eds., Kohm, K. A., and J. F. Franklin, 111-140. Island Press.

Frelich, L. E., and P. B. Reich. 1995. Spatial patterns and succession in a Minnesota southern boreal forest. *Ecological Monographs* 65:325-346.

Heinselman, M. L. 1973. Fire in the virgin forests of the Boundary Waters Canoe Area, Minnesota. *Quaternary Research* 3:329-382.

Hunter, M. L., Jr., and A. J. K. Calhoun. 1996. A triad approach to landuse allocation. In *Biodiversity in Managed Landscapes*, eds., Szaro, R., and D. Johnston, 477-491. Oxford University Press.

Kelty, M. J. 1992. Comparative productivity of monocultures and mixed-species stands. In *The Ecology and Silviculture of Mixed-Species Forests*, ed., Kelty, M. J., 125-141. Kluwer Academic Publishers.

Landres, P. B., P. Morgan, and F. J. Swanson. 1999. Overview of the use of natural variability concepts in managing ecological systems. *Ecological Applications* 9:1179-1188.

Leatherberry, E. C., and J. S. Spencer, Jr. 1994. Michigan Forest Statistics, 1993. USDA Forest Service Resource Bulletin NC-170.

Miles, P. D., C. M. Chen, and E. C. Leatherberry. 1991. Minnesota Forest Statistics, 1990, Revised. USDA Forest Service Resource Bulletin NC-158.

Nowacki, G. J., M. D. Abrams, and C. G. Lorimer. 1990. Composition, structure, and historical development of northern red oak stands along an edaphic gradient in north-central Wisconsin. *Forest Science* 36:276-292.

Palik, B. J., and K. S. Pregitzer. 1992. A Comparison of Presettlement and present-day forests on two bigtooth aspen- dominated landscapes in northern Lower Michigan. *The American Midland Naturalist* 127:327-338.

Palik, B. J., R. J. Mitchell, G. Houseal, and N. Pederson. 1997. Effects of canopy structure on resource availability and seedling responses in a longleaf pine ecosystem. *Can. J. For. Res.* 27:1458-1464.

Palik, B. J., R. J. Mitchell, and J. K. Hiers. 2002a**.** Modeling silviculture after natural disturbance to maintain biological diversity: Balancing complexity and implementation. *Forest Ecology and Management* 155:347-356.

Palik, B. J., R. J. Mitchell, S. Pecot, M. Battaglia, and P. Mou. 2002b. Spatial Distribution of Overstory Retention Influences Resource Availability and Seedling Growth: A Silvicultural Experiment using Longleaf Pine. Unpublished manuscript.

Schmidt T. L. 1997. Wisconsin Forest Statistics, 1996. USDA For. Ser. Res. Bull. NC-183.

Whitney, G. G. 1986. Relation of Michigan's presettlement pine forests to substrate and disturbance history. *Ecology* 67:1548-1559.

Eleven Year Results of a Red Pine Regional Provenance Test and Options for Converting to a Seedling Seed Orchard

Andrew J. David, Assistant Professor, Department of Forest Resources, adavid@umn.edu;
Carolyn C. Pike, Research Fellow, Department of Forest Resources; and
Robert A. Stine, Research Associate,
College of Natural Resources, University of Minnesota[1]

ABSTRACT. An 11-year-old (12 years from seed) red pine provenance trial comprised of 100 plus-tree families, collected from MN, WI and the upper peninsula of MI, was used to analyze zone, stand and family differences in height, diameter and volume. Small but significant differences were found for zone and family (diameter and volume) and for stand and family (height). Both diameter and volume of red pine sources from warmer zones were significantly better or ranked ahead of sources from northeastern Minnesota where the test was located.

Individual tree volume information was then used to compare four different selection methods in a theoretical conversion of the same provenance trial into a seedling seed orchard. Combined selection provided the highest level of estimated genetic gain for volume (9.9% at a 7% selection intensity) followed by individual selection, family plus within family selection and family selection. Family diversity, which measures the number and evenness of family representation, was calculated and used as a surrogate for genetic diversity in the seed orchard. Individual selection had a higher level of family diversity than family plus within family selection, combined selection or family selection. For each of the selection methods an optimization point was calculated, which maximized estimated genetic gain and family diversity relative to each other. In all cases these optimization points were favorably high, indicating that estimated genetic gain and family diversity are not mutually exclusive in this red pine seedling seed orchard.

KEYWORDS: red pine, provenance test, selection, genetic gain, diversity, seedling seed orchard, tree improvement

---

[1] David, A. J., C. C. Pike, and R. A. Stine. 2002. Eleven year results of a red pine regional provenance test and options for converting to a seedling orchard. In *Proceedings of the Red Pine SAF Region V Technical Conference*, eds., Gilmore, D. W., and L. S. Yount, 65-84. Staff Paper no. 157. St. Paul, MN: University of Minnesota, College of Natural Resources, Department of Forest Resources.

Introduction

Red pine is the most planted tree species in the Lake States region where it is used for a variety of timber and nontimber uses (Burns and Honkala 1990). It is also one of the most genetically depauperate forest tree species anywhere, with levels of genetic heterozygosity, allelic richness and percent polymorphic loci all lower than expected for a long-lived, monoecious, wind-pollinated species (Hamrick and Godt 1989). Despite the high interest in the species, low levels of genetic diversity, as measured by isozyme markers, (Fowler and Morris 1977) and small differences in height growth among families in range-wide and regional provenance tests have precluded much interest in breeding based tree improvement programs.

However, the amount of adaptive variation in red pine from Minnesota and Wisconsin sources has not been well tested in a regional provenance test grown in the Lake States region. Previous studies have tested small numbers of Minnesota and Wisconsin families in the context of a larger, range-wide provenance test (Wright et al. 1972), planted the sources outside the natural range of red pine (Hough 1967), or used experimental designs that were inefficient for assessing individual and family performance across the range of environmental variation on the test site (e.g., Buckman and Buchman 1962; Hough 1967). All of these trials were limited to the use of either height or diameter to assess growth potential and none have tested the utility of Lake States seed collection zones (Rudolf 1956) for assessing clinal variation in growth traits (Figure 1).

Reliable estimates of adaptive variation will require increased precision in the design of the experiment and the measurement of growth traits (Lester and Barr 1965). For example, large family trials, with a hierarchy of families, stands, and zones within a regional area will be required to adequately assess any differences in genetic structure at these levels. The experimental design must allow for sufficient sampling of site variation for all families and the traits measured must be robust enough to truly capture the response of the individuals to the site.

Despite the lack of tree breeding programs in red pine there is a desire for improved seed because even small increases in stem volume on a per tree basis result in large increases in total productivity due to the number of seedlings that are planted annually. This desire for a constant supply of improved seed can be met through the establishment of seedling seed orchards, which are a relatively easy, cost-effective method for increasing both the genetic gain and the supply of genetically improved seed (Zobel and Talbert 1984).

Estimated genetic gain, or *E(g)*, is manipulated by the selection method and intensity of selection that is used to rogue the seedling seed orchard shortly after crown closure.

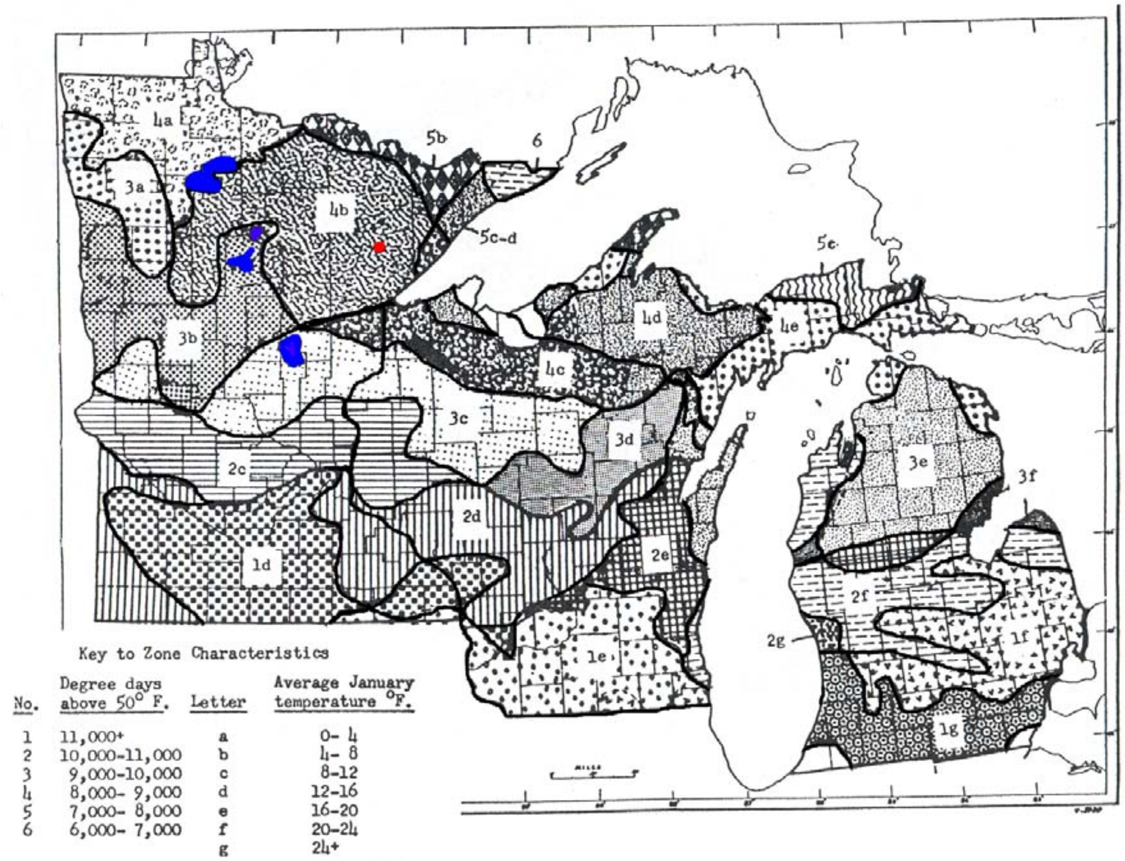


Figure 1. Forest tree seed collection zones for the Lake States as defined by Rudolf (1956).

However, rogueing also decreases the family diversity (*Fd*) and, by extension, the genetic variation found in the retained trees. This reduction in *Fd* results in a decrease in genetic diversity in the seed produced by the seed orchard, and in the seedlings used for reforestation efforts. Therefore, the selection method and intensity level used should be chosen after careful consideration of the impacts on both the diversity and genetic gain of seed produced from the orchard.

Seed orchard managers typically rely on one of four selection methods to remove undesirable trees in a seedling seed orchard. Family selection (FS) ranks families based on family means and retains all the individuals in the selected families regardless of their individual performance (Carter et al. 1990; Morris et al. 1992; Adams and Morgenstern 1991). Individual selection (IS), or mass selection, ranks each individual tree and rogues those below a minimum threshold level. Family plus within family selection (FWFS) retains a specific number of individuals in the best families (Wilson 1974; Canavera 1975). Combined selection (CS) creates an index value for each tree based on individual and family performance weighted according to individual and family heritabilities respectively. Any individual tree whose index value ranks below a minimum threshold value is then rogued (Magnussen and Yeatman 1990). Each of these selection methods will increase the expected genetic gain of a particular trait in the seedling seed orchard. However, due to differences in family representation after rogueing these selection methods will have varying effects on the family diversity.

The goals of this research were threefold. First, to analyze a red pine regional provenance test of Lake States sources planted in northeastern Minnesota for zone, stand and height differences using height, diameter, and volume measurements. Second, to evaluate the suitability of converting the regional provenance test into a seedling seed orchard by comparing the effect of four different selection methods and ten different selection intensities on estimated genetic gain and family diversity. Third, calculate for each selection method the optimal selection intensity, which maximizes both genetic gain and family diversity for each of the four selection methods.

Material and Methods

Site, Seedlings and Data Collection

The red pine regional provenance test is located in St. Louis County near Central Lakes, Minnesota at approximately 47°18' north latitude 92°29' west longitude. The site has a 0-5% slope, sandy loam soil and was formerly occupied by a mixture of quaking aspen (*Populus tremuloides*), balsam fir (*Abies balsamifera*) and paper birch (*Betula papyrifera*). The trial consists of 108 families from plus trees selected in Minnesota, Wisconsin and the northern peninsula of Michigan arrayed in single-tree plots in 24 replications for a total of 2,382 planted seedlings (not all families were fully replicated). Seedlings were planted in May 1988 as 1-0 containerized stock at 3 m x 3 m spacing and were 12 growing seasons from planting at the time of measurement.

Individual tree heights were measured to the nearest 0.1 m using a range pole and diameters were measured at 1.37 m above ground to the nearest 0.5 cm using metal calipers. Stem volume (dm^3) was calculated using a formula for total cubic foot stem volume (Ek 1985) modified to calculate volume in cubic decimeters:

$$dm^3 = \left(\left(0.42 + 0.01969(9.144 - ht)\right) \left((3.1416)\left(\frac{dbh}{2}\right)^2 (0.0001) \right) (ht) \right) (10^3)$$

where *dbh* is diameter and *ht* is total height. Eight families with low representation in the orchard (number of individuals per family less than five) were removed from analysis leaving 100 families.

ANOVA and Means Comparison for Growth Traits

Analysis of variance was performed for height, dbh and volume using PROC GLM (SAS Institute Inc. 1999) and the following model:

$$Y_{mptvx} = \mu + R_m + Z_p + S(Z)_t + F(Z*S)_v + R_m * F(Z*S)_v + E_x$$

where Y is the total tree height, dbh or volume, ì is the overall mean, R_m, Z_p, $S(Z)_t$ and $F(Z*S)_v$ are the effects of replication (m = 1…24), zone (p = 1…8), stand nested within zone (t = 1…x) and family nested within stands within zones (v = 1…100) respectively, and R_m* $F(Z*S)_v$ is the effect of the family v (nested within stand within zone) in replication m interaction and E_x is the experimental error. All factors were considered random with the exception of zone. F tests for random factors were computed utilizing the appropriate denominators as defined by the random test function of PROC GLM.

For height, dbh and volume a Tukey's test of means comparison was performed using PROC MEANS (SAS Institute, Inc. 1999) for the zone, stand(zone) and family(stand*zone) factors.

Calculation of Variance Components and Heritabilities

Variance components were estimated using PROC VARCOMP (SAS Institute, Inc. 1999) and the following model:

$$Y_{ijkl} = \mu + R_j + F_k = R_j F_k + E_l$$

where Y is the total tree volume, ì is the overall mean, R_j and F_k are the effects of replication (j = 1…. 24) and family (k = 1…. 100) respectively, R_jF_k is the effect of the family k in replication j interaction and E_l is the experimental error. Family and individual tree heritabilities were calculated using the variance components and the following formulas for family heritability

$$h_f^2 = \frac{\delta_f^2}{\frac{\delta_E^2}{R} + \delta_{RF}^2 + \delta_F^2}$$

and individual tree heritability

$$h_i^2 = \frac{(4)\delta_F^2}{\delta_E^2 + \delta_{RF}^2 + \delta_F^2}$$

where δ_F^2 is the variation due to family, δ_{RF}^2 is the variation due to the interaction between replication and family and δ_E^2 is the remainder of the genetic variation plus variation due to experimental error, and R is the number of replications.

Selection Simulation and Calculation of Optimization Points

Ten selection intensities (7%, 10%, 12%, 15%, 17%, 20%, 23%, 25%, 27% and 30%) that represent the likely range of selection intensities for a seedling seed orchard of this size were used to calculate *E(g)* for stem volume for each selection method following formulas from Falconer (1989):

individual selection

$$E(g) = i_1 \delta_P h_i^2$$

family selection

$$E(g) = i_1 \delta_P h_i^2 \left[\frac{(1+(n-1)r)}{\left(\sqrt{n(1+(n-1)t)}\right)} \right]$$

family + within family selection

$$E(g) = i_2 \delta_P h_i^2 \left[\frac{(1+(n-1)r)}{\sqrt{n(1+(n-1)t)}} \right] + i_3 \delta_P h_i^2 \left[(1-r)\sqrt{(n-1)/(l-t)n} \right]$$

combined selection

$$E(g) = i_1 \delta_P h_i^2 \sqrt{1 + \frac{(r-t)^2}{(1-t)} \times \frac{(n-1)}{(1+(n-1)t)}}$$

where i_1, i_2, *and* i_3 are the standardized selection intensities (Becker 1984) for individual, family and within family respectively, h_i^2 is the individual tree heritability, δ_P is the phenotypic standard deviation, *n* is the harmonic mean number of individuals in the selected families, *r* is the genetic correlation among half-sibs (*r* = 0.25), and *t* is the intraclass phenotypic correlation for half-sibs (*t* = 0.25).

Individual tree volumes were adjusted for differences in replication effects using the deviation from replication mean (Cotterill 1987; Cotterill and Dean 1990). Adjusted individual volumes were then used to rank individuals, determine family means and calculate the index value (*index*) for combined selection:

$$index = \left(vol_i (h_i^2) \right) + \left(vol_f (h_f^2) \right)$$

where vol_i is the volume of the individual, adjusted for replication effects, vol_f is the mean volume of the family adjusted for replication effects, and h_i^2 and h_f^2 are the individual and family heritabilities, respectively.

Family diversity, is a measure of the number and evenness of family representation, and was calculated similar to allelic diversity, *He*, (Berg and Hamrick 1997):

$$Fd = \sum_{i=1,n} (p_i)^2$$

where p_i is the frequency of the i^{th} retained family in the seed orchard.

To determine the optimum selection intensity that maximizes both *E(g)* and *Fd* for each selection method values for *E(g)* and *Fd* were plotted using a 0.0 to 1.0 relative scale and quadratic equations were used to estimate nonlinear regression lines from the data points using SigmaPlot (SPSS, Inc. 2001). An iterative process using these quadratic equations was used to determine the optimization point where both lines intersected. This point also identified the optimal number of trees to retain in the seed orchard for a particular selection method. This optimal number of retained trees was used to determine the optimal selection intensity and then used in the quadratic equations to estimate *E(g)* and *Fd* at the point of optimization.

Results

Plantation survival was high at 93.3%, the average tree height was 5.6 m, average tree diameter was 10.4 cm and the plantation average for stem volume was 27.1 dm^3.

Analysis of variance indicated that there were significant differences at the $\alpha = 0.5\%$ level for stands and families when analyzed for height and for zones and families when analyzed for both dbh and volume (Table 1). A Tukey's test comparing zones for both dbh and volume indicated that zone 2d was significantly better than 3c, the worst zone, and ranked ahead of local zone, 4b, for both dbh and volume (Table 2). Type I estimates of variance components for individual tree stem volume were made and individual $\left(h_i^2\right)$ and family $\left(h_f^2\right)$ heritabilities were calculated as 0.189 and 0.341 respectively (Table 3).

Table 1. Levels of significance for zones, stands within zones, and families within stands within zones for the St. Louis County red pine regional provenance test when analyzed for 11 year height, dbh and volume.

Source	df	Height	Dbh Pr > F	Volume
Rep	23	< 0.0001	< 0.0001	< 0.0001
Zone	7	0.2879	0.0276	0.0374
Stand (Zone)	43	0.0243	0.497	0.3185
Family (Zone*Stand)	49	0.0448	0.0005	0.0007
Rep*Family (Zone*Stand)	2072	0.2641	0.4144	0.4823

Table 2. Tukey's test of means comparison for zone averages from the St. Louis Co. red pine regional provenance test when analyzed for 11-year height, dbh and volume. TG is the Tukey's Grouping at the $\alpha = 0.5\%$ level and N is the number of individuals in a particular zone. Zone averages are significantly different if two means do not share a letter designation in TG.

Height				Dbh				Volume			
TG	**Zone**	**N**	**Mean (m)**	**TG**	**Zone**	**N**	**Mean (cm)**	**TG**	**Zone**	**N**	**Mean (dm)**
A	3a	61	18.02	A	2d	189	4.49	A	2d	189	0.98775
A	4c	110	17.99	BA	2e	68	4.46	BA	3b	835	0.98019
A	2d	189	17.92	BA	3b	835	4.46	BA	2e	68	0.97374
A	3b	835	17.91	BA	4c	110	4.43	BA	4c	110	0.96673
A	2e	68	17.84	BA	3a	61	4.40	BA	3a	61	0.96396
A	4b	690	17.83	BA	4b	690	4.37	BA	4b	690	0.94014
A	4d	85	17.62	BA	4d	85	4.32	BA	4d	85	0.91089
A	3c	173	17.55	B	3c	173	4.27	B	3c	173	0.88675

Table 3. Estimated mean squares, variance components, and calculated heritabilitis for the St. Louis County red pine seedling seed orchard.

Source	**df**	**EMS**
Rep	2399207116	Var (Error) + 1.0151 Var (Rep*Family) + 0.0945 Var (Family) + 92.067 Var (Rep)
Family		Var (Error) + 1.0134 Var (Rep*Family) + 22.077 Var (Family)
Rep*Family		Var (Error) + 1.0069 Var (Rep*Family)
Error		Var (Error)
Type I Estimates Var (Rep) = 0.0034688 Var (Family) = 0.0031476 Var (Rep x Family) = 0.0035751 Var (Error) = 0.05988		Heritabilities $h_f^2 = .341$ $h_i^2 = .189$

To compare among the four selection methods selection intensities were held constant for all selection simulations at 7%, 10%, 12%, 15%, 17%, 20%, 23%, 25%, 27% and 30%, or, in the case of FS and FWFS, as close to these percentages as possible given the constraints of family size. Although three of the four selection methods (FS, FWFS and CS) have a family component in their calculation there was a marked difference in family representation between them. Individual selection retained the highest number of families at each selection intensity and, except for FWFS, it had the lowest maximum number of individuals per family of any

selection method (Table 4). Combined selection had fewer families and a higher maximum number of individuals per family than IS at any given selection intensity. With the number of individuals per family preset at seven FWFS was the most balanced selection method, the range between minimum and maximum number of individuals per family being zero. Family plus within family selection also retained far fewer families than IS or CS but for any given

Table 4. Calculated parameters for the four selection methods and ten selection intensities.

Individual Selection										
Selection Intensity	7.0%	10.0%	12.0%	15.0%	17.0%	20.0%	23.0%	25.0%	27.0%	30.0%
# Trees retained	155	221	266	331	376	442	508	552	597	663
# Families	74	84	88	94	96	97	98	99	100	100
Max. # per family	5	8	8	10	10	10	11	12	13	13
Min. # per family	1	1	1	1	1	1	1	1	1	1
E(g)	9.7%	8.9%	8.5%	7.9%	7.6%	7.1%	6.7%	6.5%	6.2%	5.9%
Fd	0.9825	0.9841	0.9846	0.9856	0.9863	0.9871	0.9875	0.9876	0.988	0.9889
Family Selection										
Selection Intensity	7.1%	10.1%	12.2%	15.3%	17.3%	20.5%	23.4%	25.3%	27.3%	30.5%
# Trees retained	158	224	270	338	383	453	517	561	604	673
# Families	7	10	12	15	17	20	23	25	27	30
Max. # per family	24	24	24	24	24	24	24	24	24	26
Min. # per family	20	20	20	20	20	20	20	20	20	20
E(g)	9.2%	8.4%	8.0%	7.5%	7.1%	6.7%	6.3%	6.1%	5.9%	5.5%
Fd	0.8567	0.8997	0.9165	0.9332	0.9410	0.9499	0.9564	0.9599	0.9629	0.9666
Family + Within Family Selection										
Selection Intensity	7.0%	10.1%	12.0%	14.9%	17.1%	20.0%	23.1%	25.0%	26.9%	30.1%
# Trees retained	154	224	266	329	378	441	511	553	595	665
# Families	22	32	38	47	54	63	73	79	85	95
Max. # per family	7	7	7	7	7	7	7	7	7	7
Min. # per family	7	7	7	7	7	7	7	7	7	7
E(g)	9.6%	8.7%	8.2%	7.5%	7.0%	6.4%	5.8%	5.5%	5.1%	4.4%
Fd	0.9545	0.9688	0.9737	0.9787	0.9815	0.9841	0.9863	0.9873	0.9882	0.9895
Combined Selection										
Selection Intensity	7.0%	10.0%	12.0%	15.0%	17.0%	20.0%	23.0%	25.0%	27.0%	30.0%
# Trees retained	155	221	266	331	376	442	508	552	597	663
# Families	43	50	53	60	62	66	71	71	72	75
Max. # per family	15	18	19	20	21	21	22	22	23	23
Min. # per family	1	1	1	1	1	1	1	1	1	1
E(g)	9.9%	9.1%	8.7%	8.1%	7.8%	7.4%	7.0%	6.8%	6.5%	6.2%
Fd	0.9546	0.9605	0.9657	0.9705	0.9721	0.9752	0.9772	0.9785	0.9793	0.9804

selection intensity it had roughly three times the number of families found in FS. Family selection had the lowest number of families retained across all selection intensities as well as the highest maximum and minimum number of individuals per family.

For the four selection methods *E(g)* for stem volume ranged from 9.9% (CS at 7% selection intensity) to 4.4% (FWFS at 30.1% selection intensity). The combined index method always generated the largest estimated genetic gain followed by individual selection, and either family selection or family plus within family selection (Figure 2).

Family diversity (*Fd*) ranged from 0.9894 (FWFS 30.1% selection intensity) to 0.8567 (FS 7.1% selection intensity). Individual selection had the highest *Fd* value across most selection intensities while FWFS had the highest *Fd* value for the two lowest selection intensities. Family selection consistently had the lowest *Fd* value (Figure 3).

Determination of the optimal selection intensity that maximizes both *E(g)* and *Fd* was calculated for each of the selection methods (Figure 4a-d). The number of retained trees as indicated by the optimal selection intensity was then used to calculate *E(g)* for stem volume and *Fd* at the optimization point for each selection method. The four selection methods optimized *Fd* and *E(g)* at selection intensities of 6.96% (IS) to 10.14% (FS). At the optimization points *E(g)* varied from 9.66% (IS and CS) to 8.44% (FS) and *Fd* ranged from 0.983 (IS) to 0.893 (FS). Family selection had the lowest optimized *E(g)* and *Fd* values (Table 5).

Table 5. Selection intensity, number of retained trees, estimated genetic gain (*E(g)*), and family diversity (*Fd*) at the optimization point of *E(g)* and *Fd* for each selection method.

Selection Method	Selection Intensity	# Trees Retained	*E(g)*	*Fd*
Individual Selection	6.96 %	154	9.66%	0.9827
Combined Selection	7.74%	171	9.66%	0.9565
Family + Within Family Selection	7.60%	168[a]	9.32%	0.9594
Family Selection	10.14%	224[b]	8.44%	0.8932

[a] Number of trees retained was rounded down to the nearest full family from the actual optimization points of 170 trees.
[b] Number of trees retained was rounded up to the nearest complete seven-member family from the actual optimization point of 221 trees.

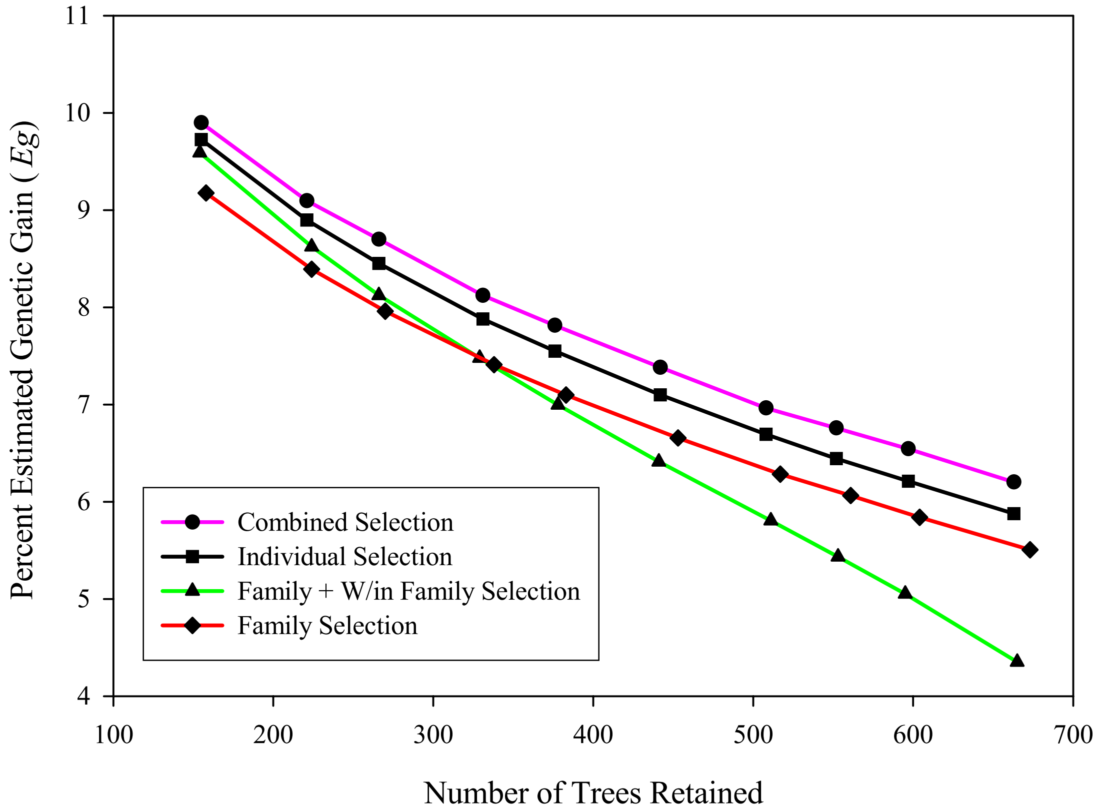


Figure 2. Estimated genetic gain for the St. Louis County red pine seedling seed orchard when rogued with four different selection methods across ten different selection intensities ranging from 7-30%.

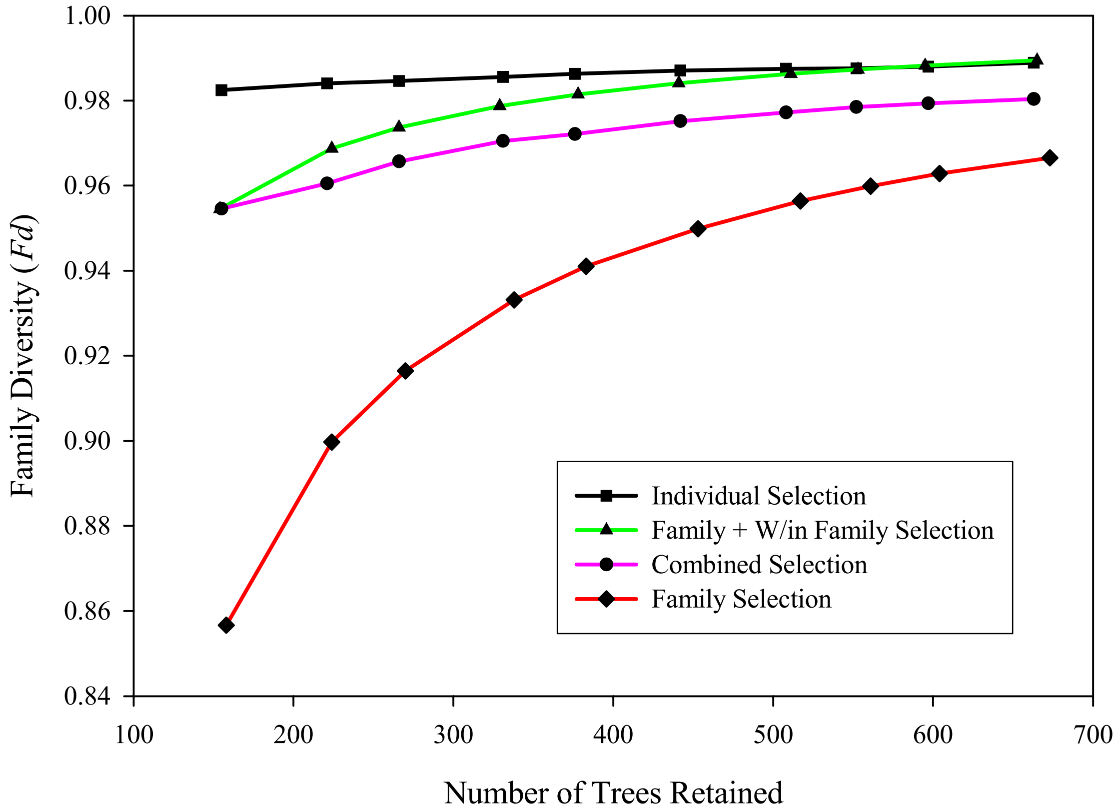


Figure 3. Family diversity for the St. Louis County red pine seedling seed orchard when rogued with four different selection methods across ten different selection intensities ranging from 7-30%.

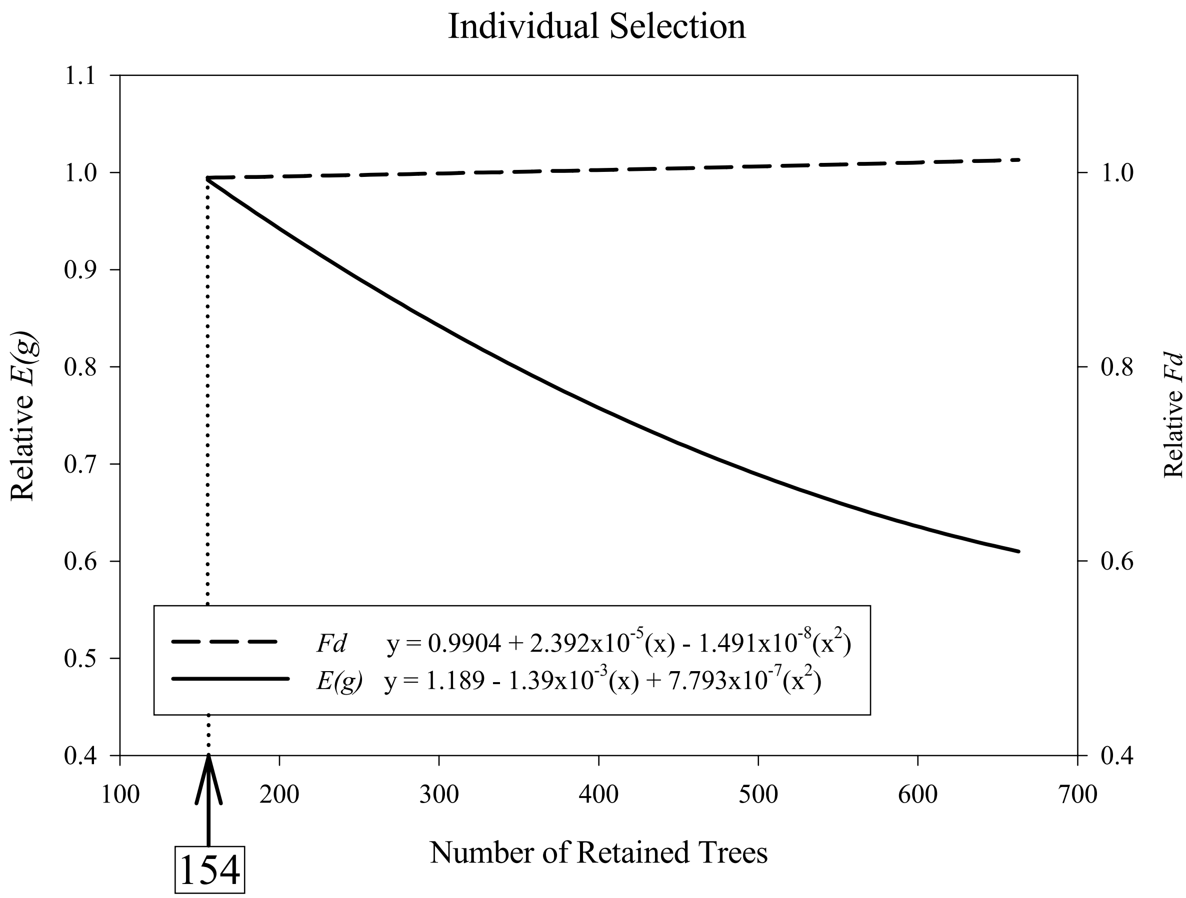


Figure 4a. Optimization point for *E(g)* and *Fd* for Individual Selection.

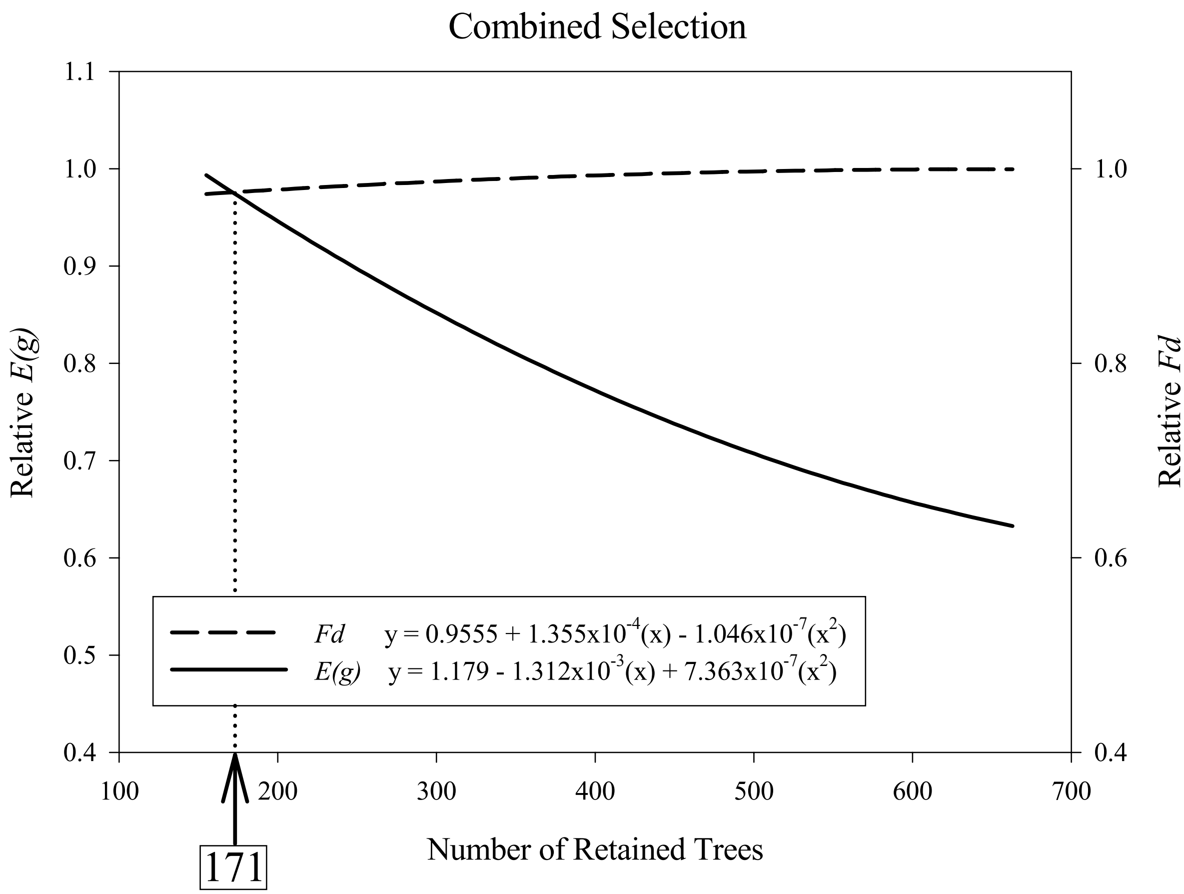


Figure 4b. Optimization point for *E(g)* and *Fd* for Combined Selection.

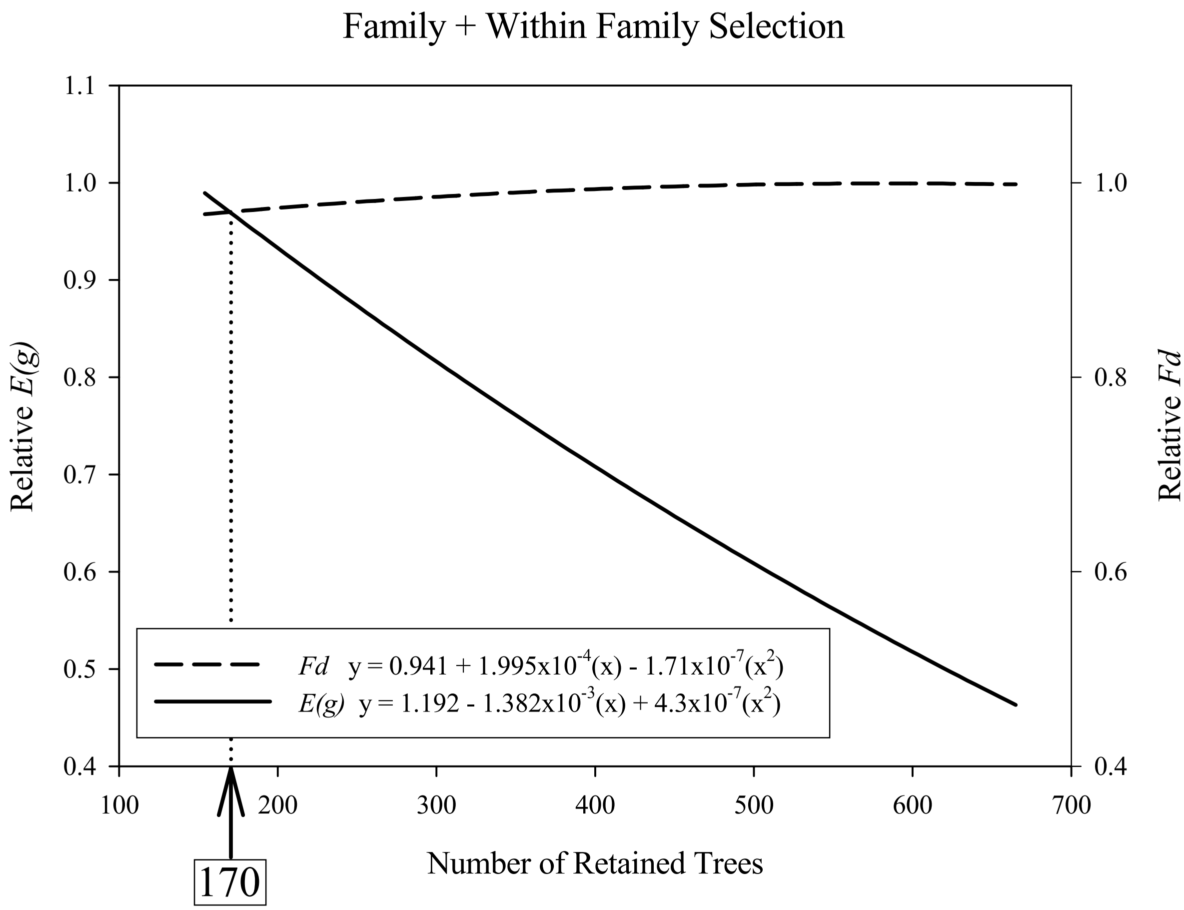


Figure 4c. Optimization point for *E(g)* and *Fd* for Family + Within Family Selection.

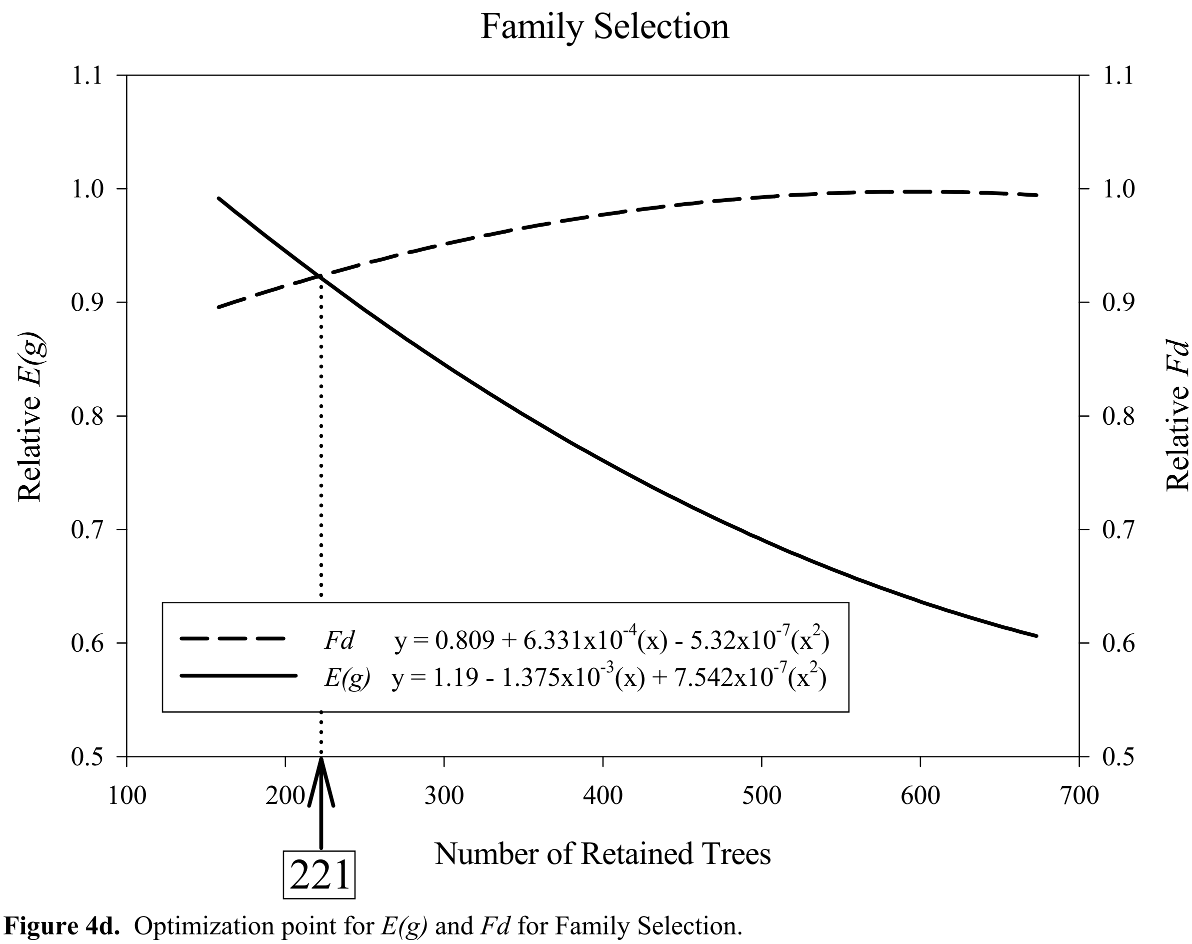


Figure 4d. Optimization point for *E(g)* and *Fd* for Family Selection.

Discussion

The high survival rate, well-balanced design (average family size equals 22.1 individuals), and uniform site conditions provided good estimates of family performance and genetic parameters for this regional provenance test. Analysis of variance indicated that there were significant differences among zones for both dbh and volume but not for height. Earlier investigations into red pine performance have used height as a growth trait and found little or no significant differences in either zones (Buckman and Buchman 1962) or families (Hough 1967) but did not investigate differences for dbh or volume. This analysis indicated that significant gains in volume could be achieved by using red pine seed from zone 2d, which encompasses portions of southeastern Minnesota and west-central Wisconsin. In this plantation families from zone 2d grew, on average, 5.0 % more volume than families from the local zone. This 5.0 % difference is of significant practical value for reforestation efforts in northeastern Minnesota, and can be achieved simply by collecting and using seed from a specific seed collection zone. Although not significantly different than the performance of zone 4b, most warmer zones did generate higher levels of volume than the local source. This suggests that seed collected from most warm zones could be expected to outperform seed collected from zone 4b. The exceptions are zone 3c (east-central Minnesota and northwestern Wisconsin) and zone 4d (western portion of the upper peninsula of Michigan) which both performed worse than seed from the local zone, 4b.

The fact that only the best and worst zones are significantly different suggests that there is little difference in family performance between zones. A check of family ranks from the Tukey's test of mean comparisons (data not shown) bears this out indicating that there are many good families in all zones and that our sampling scheme and experimental design were adequate to detect differences between zones if they existed.

Narrow-sense heritability for individual stem volume, h_i^2 = 0.189, compared favorably with other pine species such as *P. tecunumanii* (0.15), *P. oocarpa* (0.29), *P. elliottii* (0.12), *P. palustris* (0.31) and *P. caribaea* (0.11) (Hodge and Dvorak 1999; Moura et al. 1998; Dieters et al. 1995; Adams et al. 1994; Ledig and Whitmore 1981; respectively) indicating that stem volume is a trait under low to moderate genetic control in this population of red pine.

All four selection methods increased *E(g)* for stem volume indicating that improvements in volume for red pine are possible despite having an inherently low level of natural genetic variation. Across the ten selection intensities the four selection methods provided similar estimated genetic gains never varying by more than 1.8%. Combined selection, which resulted in the highest estimated stem volume gains across all selection intensities, resulted in a 9.9% increase in stem volume when applied at the 7% selection intensity. This is similar to the stem volume increase of 9.0% reported for a 290 family, ten-year-old red pine seedling seed orchard in Wisconsin (Guries and Ager 1980). Even FS and FWFS, the poorest selection methods for *E(g)*, resulted in a 9.2% and 9.6% increase in stem volume at the 7.1% selection intensity despite the inclusion of poorer performing family members in the better performing families. Individual selection consistently ranked second behind CS and ahead of FS or FWFS for *E(g)* in stem volume. The flexibility to select quality individuals from all families without being forced to select a fixed number of individuals from a family undoubtedly contributed to the higher *E(g)* for IS relative to either version of family selection.

Family diversity is a measure of the number of families and their evenness. Implicit in this measurement is the assumption that the genetic diversity of seed produced in the seedling seed orchard is reflective of the level of family diversity in the orchard after rogueing. This assumes that all seed produced is half-sib, i.e., pollination in the seed orchard is completely random. However, due to differences in flowering phenology among individuals, the amount of male and/or female flowers produced among individuals, and the amount of foreign pollen entering the seed orchard, the actual level of sib mating is unknown. Therefore, comparisons between selection methods based on *Fd* are used only in a relative manner.

Selection methods are ranked differently for *Fd* across the range of selection intensities due to the manner in which families are represented in each selection method. Individual selection had the highest *Fd* value of any selection method for all but the lowest two selection intensities because it retained a few individuals from a large number of families. It was the only selection method that retained all 100 families at any selection intensity (27.0%

and 30.0%), and even at the highest intensity of selection (7.0%) IS retained 74 different families, which was 31 more families than CS the next closest selection method. The large number of included families in IS was influenced by the low level of family differentiation (data not shown). Family + within family selection retained a large number of families in each selection intensity and at seven individuals per family all families are equally represented. However, because it retained fewer families than IS it ranked behind IS for all selection intensities except 27.0% and 30.0%. Combined selection retained more families than FWFS but fewer than IS resulting in a higher range of individuals per family than IS. Consequently, CS ranked third for *Fd* at all selection intensities. Family selection had the lowest *Fd* values of any selection method because the retention of all individuals in a family meant that only a small number of families could be retained (Table 2).

In this population of red pine the driving force behind high levels of *E(g)* and *Fd* appears to be how each selection method handles family representation. Selection methods with the most flexibility regarding family representation, i.e., IS and CS, provided relatively high values for *E(g)* and *Fd* while the other two selection methods FWFS and FS, which are fairly rigid in their determination of family inclusion, generally had lower levels of *E(g)* and *Fd.*

Optimization points for the four selection methods ranged in selection intensity from 6.96% (154 trees) to 10.14% (224 trees). This level of selection intensity results in fairly high values for both *E(g)* and *Fd* indicating that the two are not mutually exclusive. The actual optimization points for FS and FWFS could not be used because selection intensities had to be adjusted to accommodate complete families in both selection methods. The overall impact of changing the selection intensities for these two selection methods is negligible as the change in number of retained trees was two for FWFS and three for FS (Table 3). The little differentiation in optimization points between the four selection methods is a function of the low level of family differentiation (data not shown). If family differentiation had been stronger *Fd* for CS and IS would have been lower due to increased selection in the better families resulting in a lower optimization point for these two selection methods.

When optimized both IS and CS had the highest *E(g)* value for stem volume but IS had a higher *Fd* value despite having 17 fewer trees (Table 3). From an operational standpoint this is very important because the choice of IS as a rogueing method would result in the highest *E(g)*, the highest *Fd* and fewest trees to manage of any of the four selection methods. At its optimization point FWFS had the second highest *Fd* and was marginally worse than IS and CS for *E(g)*. Family selection was clearly the worst selection method for rogueing the seedling seed orchard. At its optimization point it resulted in the lowest *E(g)* value, the lowest *Fd* value and the highest number of trees to manage.

The results presented here demonstrate how different selection methods and selection intensities can impact population parameters such as *E(g)* and *Fd* even in a species with relatively little genetic differentiation. Because *E(g)* and *Fd* vary according to the selection method and intensity chosen it is necessary to have a clear understanding of the objectives and limitations of the orchard owner prior to rogueing. For example, if genetic gain is the priority then CS is the selection method of choice. If family diversity is the major priority then IS or FWFS would be the best selection method depending on the selection intensity desired. If both *E(g)* and *Fd* are equal priorities then an optimization strategy such as was outlined here is an effective way to determine an appropriate selection intensity. Additionally, specific information about the estimated seed needs for reforestation, a species' ability to tolerate inbreeding (high for sib-mating in red pine, Fowler 1965), or the availability of personnel to manage trees and harvest cones may impact the selection method and intensity that are chosen. Clearly, multiple factors can play an important role in determining which selection method and intensity to select when rogueing a seedling seed orchard.

It should be noted that the measurements and selection simulations are based on 13-year-old trees that have not reached rotation age. Growth patterns of individuals and/or families may assert themselves later in the rotation, or they may become less distinct, changing the individuals or families that would be retained. Height and stem volume calculations made on red pine seedling seed orchards in Wisconsin indicated that families and stands were a significant source of variation at age six but that by age ten stands had become a nonsignificant source of variation (Lester 1976; Guries and Ager 1980). Regardless, after 12 growing seasons in the field selection in this seedling seed orchard was early but necessary to retain full crowns for maximizing seed production. Earlier measurements, if they had been made, may have detected a trend regarding family differentiation and indicated whether family differences could be expected to increase or decrease in this population of red pine.

Literature Cited

Adams, G. W., and E. K. Morgenstern. 1991. Multiple-trait selection in jack pine. *Can. J. For. Res*. 21:439-445.

Adams, W. T., T. L. White, G. R. Hodge, and G. L. Powell. 1994. Genetic parameters for bole volume in longleaf pine: large sample estimates and influences of test characteristics. *Sil. Genet.* 43(5-6):357-366.

Becker, W. A. 1984. *Manual of Quantitative Genetics*. 4th ed. Pullman, WA: Academic Enterprises, 190 p.

Berg, E. E., and J. L. Hamrick. 1997. Quantification of genetic diversity at allozyme loci. *Can. J. For. Res.* 27:415-424.

Buckman, R. E., and R. G. Buchman. 1962. Red pine plantation with 48 sources of seed shows little variation in height at 27 years of age. Tech. Note Lake St. For. Exp. Sta. no. 616.

Burns, R. M., and B. H. Honkala, tech. coords. 1990. *Silvics of North America: Volume 1 Conifers.* Agriculture Handbook 654. Washington, D.C.: USDA, Forest Service. 675 p.

Canavera, D. S. 1975. Variation among the offspring of selected lower Michigan jack pines. *Sil. Gen*. 24:12-15.

Carter, K. K., G. W. Adams, M. S. Greenwood, and P. Nitschke. 1990. Early family selection in jack pine. *Can. J. For. Res*. 20:285-291.

Cotterill, P. P. 1987. Short note: On estimating heritability according to paractical applications. *Sil. Genet*. 36:46-48.

Cotterill, P. P. and C. A. Dean. 1990. *Successful tree breeding with index selection*. Victoria, Australia: CSIRO Publications, 80 p.

Dieters, M. J., T. L. White, and G. R. Hodge. 1995. Genetic parameter estimates for volume from full-sib tests of slash pine (*Pinus elliottii*). *Can. J. For. Res*. 25(8):1397-1408.

Ek, A. R. 1985. A formula for the total cubic foot stem volume of small trees in the lake states. *North. J. App. For*. 2:3.

Falconer, D. S. 1989. *Introduction to quantitative genetics*. 3d ed. New York, NY: John Wiley & Sons, Inc. 438 p.

Fowler, D. P. 1965. Effects of inbreeding in red pine, *Pinus resinosa* Ait., II. Pollination studies. *Silv. Genet*. 14(1):12-23.

Fowler, D. P., and R. W. Morris. 1977. Genetic diversity in red pine: evidence for low genic heterozygosity. *Can. J. For. Res*. 7:343-347.

Guries, R., and A. Ager. 1980. Red pine seedling seed orchards: 10 year results. Forestry Research Notes no. 242. Madison, WI: Department of Forestry, University of Wisconsin.

Hamrick, J. L., and M. J. W. Godt. 1989. Allozyme diversity in plant species. In *Plant Population Genetics, Breeding and Genetic Resources*, eds., Brown, A. H. D., M. T. Clegg, A. L. Kahler, and B. S. Weir, 43-63. Sunderland, MA: Sinauer Press.

Hodge, G. R., and W. S. Dvorak. 1999. Genetic parameters and provanance variation of *Pinus tecumumanii* in 78 international trials. *For. Gen*. 6(3):157-180.

Hough, A. F. 1967. Twenty-five-year results of a red pine provenance study. *For. Sci.* 13(2):156-166.

Ledig, F. T., and J. L. Whitmore. 1981. Heritability and genetic correlations for volume, foxtails, and other characteristics of Caribbean pine in Puerto Rico. *Sil. Genet*. 30(2-3):88-92.

Lester, D. T. 1976. Height growth of red pine families in seedling seed orchards 6 years after planting. Forestry Research Notes no. 196. Madison, WI: Department of Forestry, University of Wisconsin.

Lester, D. T., and G. R. Barr. 1965. Provenance and progeny tests in red pine. *For. Sci*. 11(3):327-340.

Magnussen, S., and C. W. Yeatman. 1990. Predictions of genetic gain from various selection methods in open pollinated Pinus banksiana progeny trials. *Silv. Genet*. 39(3/4):140-153.

Morris, D. M., W. H. Parker, and R. Seabrook. 1992. Some considerations when selecting young jack pine families using growth and form traits. *Can. J. For. Res*. 22:429-425.

Moura, V. P. G., W. S. Dvorak, and G. R. Hodge. 1998. Provanance and family variation of *Pinus oocarpa* grown in the Brazilian cerrado. *For. Ecol. Mgt.* 109(1-3):315-322.

Rudolf, P. O. 1956. A basis for forest tree seed collection zones in the Lake States. *Proceedings of the Minnesota Academy of Science* 24:20-28.

SAS Institute, Inc. 1999. *The SAS system, version 8*. Cary, NC: SAS Institute, Inc.

SPSS Inc. 2001. *SigmaPlot version 7.0.* Chicago, IL: SPSS Inc.

Wilson, S. P. 1974. An experimental comparison of individual, family, and combination selection. *Genetics* 76:823-836.

Wright, J. W., R. A. Read, D. A. Lester, C. Merritt, and C. Mohn. 1972. Geographic variation in red pine: 11-year data from the north central states. *Sil. Genet*. 21(6):205-210.

Zobel, B., and J. Talbert. 1984. Applied forest tree improvement. New York, NY: John Wiley & Sons, Inc. 505p.

Wildlife Habitat and Red Pine

Ronald G. Eckstein[1]
Wildlife Biologist, Wisconsin Department of Natural Resources,
Rhinelander, WI 715-365-8999 eckstr@dnr.state.wi.us

ABSTRACT. The forests of the Upper Great Lakes support a wide variety of wildlife. Wildlife species use habitats that include pine barrens, sapling stands, mature forests, and old growth. The type and variety of wildlife that can be found in any given habitat will depend on the landscape context plus the specific composition and structure of the plant community in that habitat. Individual animals find the basic requirements of food, water, cover, and space in a relatively small area. Populations of animals find suitable habitat in a much larger area. All wildlife species exist in populations so the elements of population dynamics need to be considered. The land manager first considers the overall landscape context of the forest community and the type of wildlife that particular landscape can support. The next consideration is the habitat requirements of those wildlife species of interest. Finally, the land manager works with the plant community composition and structure to develop the habitat characteristics needed by the wildlife species of interest. Many existing red pine stands occur as plantations. The usual way to increase wildlife populations in plantations is to increase the tree species diversity and the structural diversity in the stand. This process usually involves opening the canopy in a way that allows grasses, forbs, shrubs, and saplings to develop on the forest floor.

KEY WORDS. Wildlife, habitat, red pine.

Wildlife Populations and Landscapes

Foresters view the forest in terms of forest stands and forest compartments. Wildlife biologists view the forest in terms of habitats and animal populations. A habitat is a place where a population of animals finds food, cover, water, and space to live. Animals choose as their preferred habitat a broad region (such as northern Wisconsin), a landscape within the region (such as the sand plain of Douglas County), and a niche within the landscape (such as a few acres of a young red pine plantation). All three scales should be considered when planning to conserve a full range of wildlife habitats.

A population is group of animals living and breeding in a certain area. The population can be assigned a rate of birth and a rate of death. In the better habitats where food, cover, water, and space is well distributed and of high quality the population can thrive and births will

[1] Ecktein, R. G. 2002. Wildlife habitat and red pine. In *Proceedings of the Red Pine SAF Region V Technical Conference*, eds., Gilmore, D. W., and L. S. Yount, 86-89. Staff Paper no. 157. St. Paul, MN: University of Minnesota, College of Natural Resources, Department of Forest Resources.

exceed deaths. The population can grow and export individuals to surrounding habitats. This area is a source habitat. On the other hand, if the basic habitat requirements are poorly distributed or of low quality the habitat can be a sink where deaths exceed births and the population declines. Managing wildlife populations requires the land manager to think about wildlife habitat and wildlife populations well beyond the stand (local habitat) to include the larger landscape and the landscape's place in the larger region.

About 389 species of terrestrial vertebrates live in the Upper Great Lakes (Benyus et al. 1992). These species use a wide variety of habitats including the full range of successional habitats on all sites. These habitats include everything from pine barrens to seedling and sapling stands to pole and mature stands to old growth. All these successional stages are important in the conservation of all the 389 species of terrestrial vertebrates.

Wildlife and Forests: The Two General Rules

If you were a forest, two big events would have a tremendous influence on you. One event is the opening of your forest canopy and sunlight allowed to reach the forest floor. The other big event is the restriction of sunlight when your canopy closes. Foresters are like photographers. They work with the range of light. Light in the forest makes all the difference. By manipulating the canopy, foresters can change the structure and composition of the plants and animals that live in the forest.

There are two basic rules for managing forests for wildlife. The first rule is, whenever possible, manage for the greatest diversity of tree species in forest stands. There are more than 130 large and small tree species in southern Illinois but only about 30 in northern Wisconsin. Many stands have only five or six tree species and some stands have only two or three. Wildlife species diversity goes up in stands with the greatest number of tree species.

The second basic rule is, whenever possible, manage for a diverse vegetation structure in forest stands. In clearcuts retain reserve trees as individuals or in clumps. Oaks, cherries, white pine, and rare trees are good candidates for reserve trees in clearcuts. In selectively cut stands manage for as much vertical height diversity as possible including forbs, shrubs, saplings, mid-canopy, canopy, and super canopy trees. In all stands manage for as many large snags, den trees, and as much coarse woody debris as possible.

By following the two basic rules of working with light to influence composition and structure, foresters can maintain quality habitat and conserve populations of most of the regional wildlife species.

The Property Plan

The two general rules cannot be followed in all cases. Certain species of plants and animals require very specific habitats such as large open barrens for sharp-tailed grouse or undisturbed white cedar forests for Calypso orchids. A plan is needed to manage for those species with special habitat requirements.

Most public lands have some sort of planning mechanism to guide land management activities. These property plans are the logical place to organize information on regional landscape characteristics including landforms, land type associations, natural disturbance regimes, and the special habitat requirements of some plants and animals. A good plan will help determine the role that each public land unit can play in the regional landscape. Some units may be managed for early successional habitats while others for old growth habitats. No one public land unit can be all things for all wildlife. Instead each public land unit can provide a range of habitats and successional stages best fitted to its soils and landform. By viewing the region in terms of landscapes and then landscapes in terms of various scales of time and space, land managers can maintain the full range of those 389 species of terrestrial vertebrates across a broad region (Wisconsin Department of Natural Resources, 1995).

Wildlife and the Red Pine Plantation

Wisconsin has very little natural red pine. Today, the red pine type (stands having more than 50% of the basal area in red pine) makes up only 4% of Wisconsin's forests and most of that acreage is in plantations (Schmidt 1996). Red pine plantations can dominate some local areas with sandy soils.

In Wisconsin red pine is used on public and private land to reforest old fields and small grassy openings. In addition, some aspen forests are converted to red pine. Foresters and wildlife biologists are at odds because the open grassy habitats and the aspen habitats are considered important to a variety of wildlife. Grassland birds are declining throughout the region and aspen forests are the best habitat for forest game species. An important issue facing foresters and wildlife biologists is deciding how much grassland and aspen will remain in various landscapes. A regional landscape plan is the best tool to make these important decisions.

All stands of trees, including red pine plantations, go through a sequence of changes in composition and structure as they grow from seedling stands through the pole stage to mature and old growth. For most plants and animals the stand with the poorest overall habitat is the pole stage. In this stage the competition for space and light is greatest. In pole-sized plantations the tree species diversity is generally low and the forest structure is very simple. Generally, red pine plantations established on old fields are particularly low in plant and animal diversity. Plantations established on sites formerly forested with aspen or white birch have a much richer plant and animal composition right from the start.

During the first 6 to 8 years of a new red pine plantation the open country plants and animals find suitable habitat. This is particularly true if the young plantation has scattered low snags, scattered hardwood clumps, and scattered frost pockets. After 10 years the forest canopy closes and plant and animal diversity declines. Diversity will remain low until the second thinning when the canopy is again opened up enough to allow significant light to reach the forest floor. There are many ways to diversify red pine plantations (Hartley 2002). The forester can, depending on the overall property management objectives, be very creative and work with sunlight and canopy to diversify the vegetative composition and structure of red pine plantations.

Despite the reservations of wildlife biologists, red pine plantations do have an important role in reforestation of old fields. It all depends of the landscape or forest plan. If the plan for a particular area is to manage for forest rather than grassland, then red pine is often used to reforest the site. After reforestation, the plantation is then managed to increase tree species diversity and stand structure.

A variety of forces will work to help the forester diversity the plantation. Blue jays will bring in acorns. Other birds will deposit all sorts of shrub and tree seeds. Seeds will rain in from the surrounding forest. Foresters, by opening up the canopy here and there, can work to let the sun shine in and allow new seedlings to develop. Eventually the plantation can move to a mixed stand with a diversity of tree species adapted to the site.

Literature Cited

Benyus, J. M., R. R. Buech, and M. D. Nelson. 1992. Wildlife in the Upper Great Lakes Region: A community profile. USDA Forest Service Res. Pap. NC - 301. 27 p.

Hartley, M. J. 2002. Rationale and methods for conserving biodiversity in plantation forests. *Forest Ecology and Management* 155:81-95.

Schmidt, T. L. 1997. Wisconsin Forest Statistics, 1996. USDA Forest Service Res. Bull. NC-183. 150 p.

Wisconsin Department of Natural Resources. 1995. Wisconsin Biodiversity as a Management Issue, A Report to Department of Natural Resources Managers. Madison, WI. 240 p.

Application of a Density Management Diagram for Lake States Red Pine Management

Timothy J. Mack and Thomas E. Burk[1]
Graduate Student and Professor, respectively, University of Minnesota,
Department of Forest Resources, 115 Green Hall,
1530 Cleveland Ave. N., St. Paul, MN, 55108-6112
(612) 625-0298 or (612) 624-6741 E-mail: mack0224@umn.edu or tburk@umn.edu

ABSTRACT. Density Management Diagrams (DMD's) are popular tools for developing management prescriptions for even-aged stands. While DMD's are effective tools, the traditional approach does have several drawbacks. We propose a model-based DMD for red pine in the Lake States which circumvents several weaknesses. *Resinosa* is a spreadsheet-based DMD which allows the forester to interactively compare various management options. Simulations between various pulpwood and sawlog regimes are presented which demonstrate *Resinosa's* capabilities.

KEY WORDS. Red Pine, Thinning, Density Control, Density Management Diagram.

The Density Management Diagram

Foresters manage stands to meet a variety of management objectives. Often these objectives involve the production of one or more types of merchantable yield such as pulpwood, poles, or sawlogs. In cases where timber production is the objective, management often focuses on maximizing volume production for the product or products in question. This usually involves encouraging growth on some collection of desirable trees, while capturing mortality from the less vigorous ones. Density control is the primary means by which this is accomplished.

Density Management Diagrams (DMD's) are popular tools for developing management prescriptions for even-aged stands. Their popularity stems from their ability to easily incorporate the ecological principle of self-thinning, or competition induced mortality, which provides the stimulus for thinning. Reineke (1933) was one of the first to introduce the concept of self-thinning. He showed that stands of a given average diameter do not exceed a corresponding maximum density. When graphed in log/log scale (Figure 1), this relationship

[1] Mack, T. J., and T. E. Burk. 2002. Application of a density management diagram for Lake States red pine management. In *Proceedings of the Red Pine SAF Region V Technical Conference*, eds., Gilmore, D. W., and L. S. Yount, 90-95. Staff Paper no. 157. St. Paul, MN: University of Minnesota, College of Natural Resources, Department of Forest Resources.

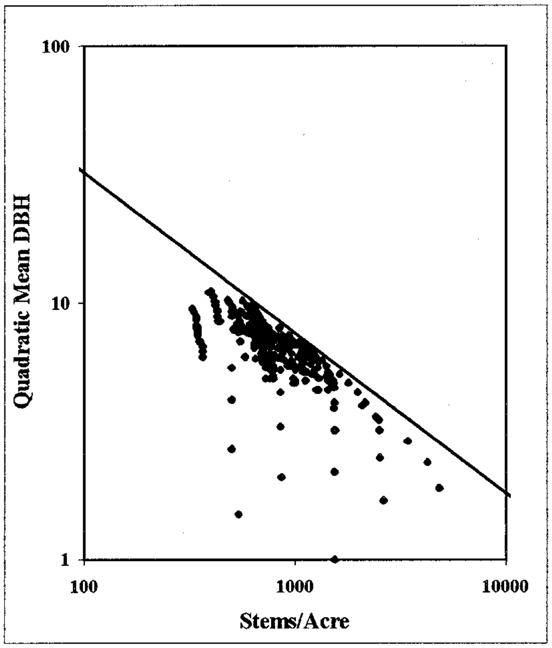


Figure 1. The diameter-density relationship for red pine stand from across the Lake States.

can be approximated by a straight line, which forms the upper boundary for maximum density. Stands within a region parallel to and just below the maximum density line are said be self-thinning. That is, they are experiencing competition induced mortality.

The focus of management, or density control, is to prevent stands from reaching the zone where self-thinning can occur. Typically, with a DMD the strategy is to maintain stands below the region of self-thinning, within a "management region" parallel to the maximum density line, but above the point of canopy closure (Figure 2).

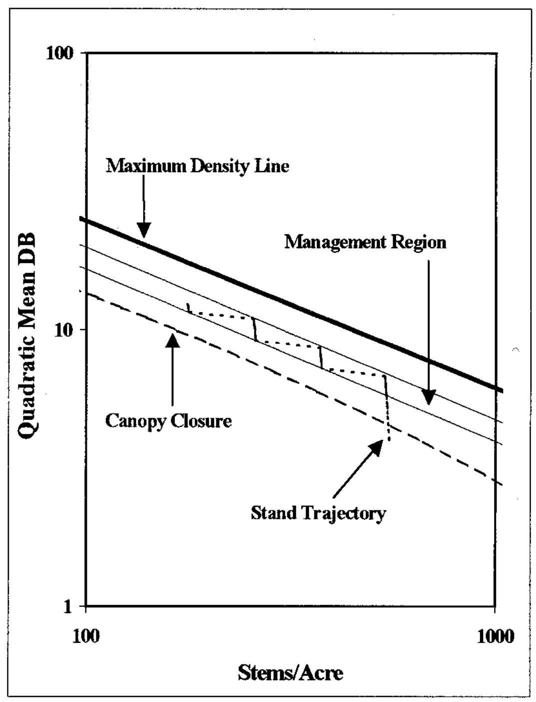


Figure 2. The development of a 60-year-old managed red pine stand.

Management objectives dictate the placement of management regions, which in turn, determine how stands grow and develop. When deriving management regions, foresters must consider the takeoff between overall stand growth and individual tree growth. Both types of growth are density dependent, while also somewhat mutually exclusive. Stands maintained at higher relative densities, closer to maximum density, exhibit higher overall stand growth (Figure 3), while stands maintained at low relative densities exhibit higher individual tree growth (Figure 4), at the expense of overall stand growth. With the DMD approach, stands managed for maximum fiber production, or pulpwood, are carried higher on the chart, as opposed to stands managed for sawlogs, which are carried lower on the chart in order to maximize individual tree growth.

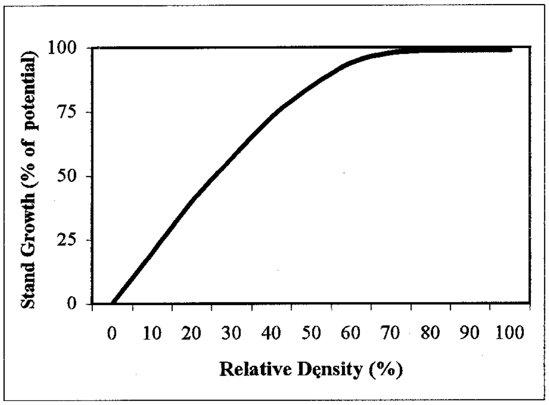


Figure 3. The relationship between overall stand growth and stand relative density. Adapted from Long (1985).

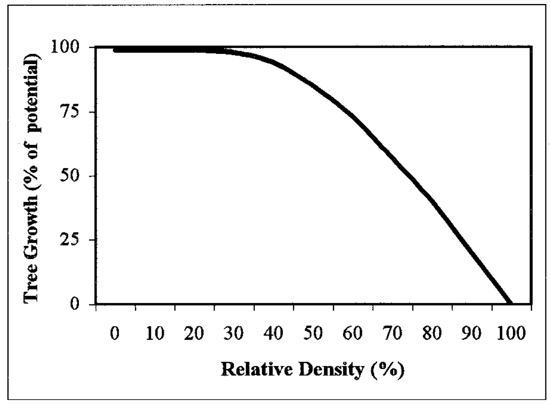


Figure 4. The relationship between individual tree growth and stand relative density. Adapted from Long (1985).

Problems with Traditional DMD's

While DMD's are effective tools, the traditional approach to their application has several drawbacks. First, the traditional DMD approach fails to account for mortality which occurs at all stages of stand development. Traditional applications assume no competition-based mortality. While this assumption is practical if stands are constantly managed at lower densities, it becomes problematic for stands carried at higher densities.

Second, a traditional DMD directly tracks the relationship between average tree size and density, independent of age. This means that age must be indirectly derived from average size and density. This is typically done through a system of equations which predict age, given mean tree size, stand density, and site index. These, typically static system of equations, result in inconsistent age prediction.

Third, management decisions require predictions of merchantable product volume. Like age, volume must be predicted indirectly with the traditional DMD approach.

Finally, most DMD's are designed to account for single product yields. Typically they will provide an estimate of pulpwood or sawlog yield, but not both. This is a drawback since many species, such as red pine in the Lake States, are merchandized for multiple products. Furthermore, product merchantability standards are usually fixed, preventing the user from defining merchantability standards of particular interest to them.

An Alternate Approach to DMD Implementation

While the DMD presented here is not the first attempt for red pine (Smith and Brand 1989; Smith and Woods 1997), it is the first red pine DMD to successfully circumvent the problems described above. *Resinosa* is a spreadsheet-based DMD for Lake States red pine which allows the forester to interactively compare various management options. *Resinosa*'a strength is that it is a model-based approach. Mortality, age, product volumes, and merchantability standards are handled directly by a system of equation which make up the growth and yield model. Potential inconsistencies between management scenarios are avoided.

Minimum required inputs for a simulation include trees per acre, average stand diameter, and site index. User defined merchantability specifications for up to two products are allowed. The user also specifies the upper and lower management lines for the management region, as well as the point at which final harvest occurs. Another option bypasses the use of management regions completely, allowing users to run custom management scenarios.

Resinosa's primary output is the DMD, including the stand's trajectory (Figure 5). The graph of the DMD is interactive, allowing the user to point to any position on the stand's trajectory and receive immediate point-in-time estimates of stand condition, growth, and yield. Secondary graphs are produced for average diameter, stems per acre, basal area, yield, and increment over time. A tabular, year by year detailed report of model outputs is also available to the user. Finally, if the user is willing to provide additional cost assumptions, *Resinosa* is capable of performing a detailed discounted cash flow analysis of most any management scenario.

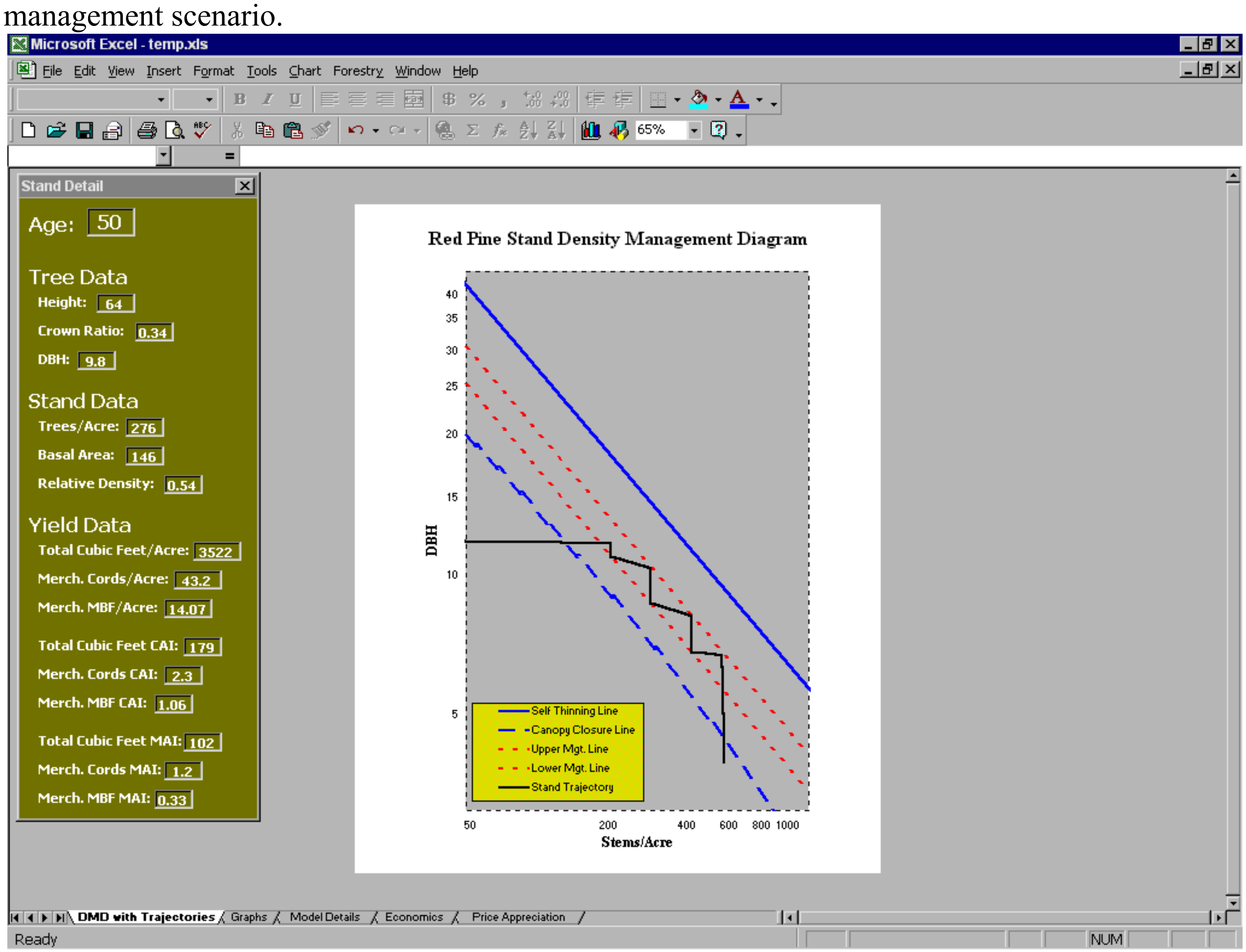


Figure 5. Sample DMD output from *Resinosa*.

Red Pine Management Examples

Simulations were conducted examining various pulpwood and sawlog management regimes to demonstrate *Resinosa's* capabilities. Three alternatives were simulated for 60 year pulpwood rotations. The first involved a constant basal area approach, where the stand was maintained between set upper and lower basal areas of 160 and 120 square feet, respectively. The second followed a method described by Lundgren (1981), in which the stand is thinned back to 120 square feet every ten years until final harvest. The third utilized the traditional DMD approach in which the stand was maintained within a management region, bound by relative densities of 47% and 60%. Overall pulpwood yield results were similar (Table 1), with the DMD approach producing slightly less cordwood volume but larger trees.

The second comparison was made between two 60 year sawlog regimes. Here, both stands were managed using a DMD approach in which the management region was bounded by relative densities of 40% and 52%. The first stand assumed an establishment density of 800 trees per acre, while the second assumed 400 trees per acre. Both scenarios produce cordwood volumes similar to the pulpwood scenarios (Table 2), but with much larger diameters. The stand established with 400 trees per acre produced trees nearly one inch larger in size at 60 years. In terms of sawlog production, it outperformed the higher density stand by 50 board feet per year, for a total difference of 3,000 board feet over the rotation.

Table 1. Results from the comparison of various thinning regimes for a 60-year pulpwood objective.

Stand comparison	BA 120-160	Lundgren 120 BA	DMD approach
DBH (inches)	10.3	9.9	11.5
Trees/acre	270	309	206
Stem wood 60 year MAI (cu ft)	122	123	118
Pulpwood 60 year MAI (cords)	1.36	1.36	1.31
Sawtimber 60 year MAI (BF)	360	370	400

Table 2. Results from the comparison of various thinning regimes for a 60-year sawlog objective.

Stand comparison	800 trees	400 trees
DBH (inches)	13.2	14
Trees/acre	143	134
Stem wood age 60 MAI (cu ft)	114	106
Pulpwood age 60 MAI (cords)	1.3	1.3
Sawtimber age 60 MAI (BF)	420	470

Summary

Red pine can be managed for a multitude of objectives under numerous regimes. Because of this, matching the proper management regime with a given objective can be challenging. *Resinosa* is designed to assist foresters in making this decision. The intent is not to dictate some magical prescription for red pine, but to provide foresters with a means for easily comparing and understanding the tradeoffs between alternative management regimes. Because *Resinosa* model is based, it avoids the problems common to the traditional DMD approach. Future work is necessary to better understand the extent of the self-thinning region for red pine, which would lead to improved formulations of the management regions.

Copies of *Resinosa* can be obtained from Thomas E. Burk.

Literature Cited

Long, J. N. 1985. A practical approach to density management. *Forestry Chronicle* 61:23-27.

Lundgren, A. L. 1981. The effect of initial number of trees per acre and thinning densities on timber yields from red pine plantations in the Lake States. North Central Forest Experiment Station. Research Paper NC-193.

Reineke, R. L. 1933. Perfecting a stand-density index for even-aged forests. *Journal of Agricultural Research* 46:627-638.

Smith, D. J., and M. E. Woods. 1997. Red Pine and White Pine Density Management Diagrams for Ontario. Ontario Ministry of Natural Resources Southcentral Sciences Section. Technical Report No. 48.

Smith, N. J., and D. G. Brand. 1987. Compatible growth models and stand density diagrams. In *Forest Growth Modeling and Prediction*, eds., Ek, A. R., S. R. Shifley, and T. E. Burk, 636-643. USDA Forest Service General Technical Report no. NC-120.

Insect Considerations in Red Pine Management

Steven A. Katovich[1]
Forest Entomologist, USDA Forest Service,
St. Paul, MN 55108 (651) 649-5264 skatovich@fs.fed.us

ABSTRACT. Prior to the 1980s the most significant insects reported on red pine were often associated with very young plantations. These insects included white grubs, Saratoga spittlebug, root collar weevil, and several different sawflies. Over the past 20-30 years fewer problems with these insects have been reported, probably because of a decline in planting programs and a corresponding increase in the age of the red pine resource. Several insects have become more prevalent, including bark beetles and the red pine shoot moth, insects associated with older red pine trees. Red pine shoot moth was initially identified as a pest in the mid-1980s in the central region of Wisconsin. Shoot feeding resulted in significant height and radial growth losses. Tree crowns became bushy and flat-topped. Pine bark beetles in the genus *Ips* have caused tree mortality following periods of drought. Bark beetles along with the several weevil species were reported to be closely associated with the decline syndrome referred to as red pine pocket decline. A potential new pest is the pine shoot beetle, a native of Europe. In Michigan it has been reported successfully attacking red pine though the presence of Scotch pine, its native host, has always been linked with outbreaks. At this time, pine shoot beetle is present throughout Lower Michigan, and the eastern Upper Peninsula. Widespread needle defoliation in red pine is uncommon. Jack pine budworm has caused damage in localized areas and several sawfly species undergo localized outbreaks. Red pine cone beetle is a pest of developing cones. This insect could reduce the likelihood for natural regeneration in red pine.

KEY WORDS. insects, red pine, *Pinus resinosa*, pests

Introduction

Management guides have viewed red pine as a species with fewer insect related concerns than other Lake States conifers (Benzie 1977; Eyre and Zehngraff 1948). It does not have a major defoliator such as the jack pine budworm or spruce budworm that attack jack pine, balsam fir and white spruce. Further, when compared with white pine, it does not have a single, major insect pest such as the white pine weevil that influences strongly the options available for management of the species. Though it does not have what many would regard as a major insect pest, an array of insects can cause problems in localized areas. Plantation failures and significant growth loss caused by insects can occur. In many instances, damage from insects such as white grubs, Saratoga spittlebug and root collar weevil are all quite

---

[1] Katovich, S. A. 2002. Insect considerations in red pine management. In *Proceedings of the Red Pine SAF Region V Technical Conference*, eds., Gilmore, D. W., and L. S. Yount, 96-106. Staff Paper no. 157. St. Paul, MN: University of Minnesota, College of Natural Resources, Department of Forest Resources.

predictable. Site conditions conducive to these insects and other pest species have been described and therefore, managers should be able to identify and avoid sites that pose a high risk.

Because red pine has largely been managed in monoculture plantations, concerns do exist from an insect and disease perspective. Any tree species managed in relatively pure stands is inherently at risk. This is further compounded by the limited genetic diversity found in red pine. Fortunately, no major insect threatens the existing resource at this time, though that could change with the introduction of an exotic species.

In regards to red pine, the most common damaging insects have been associated with seedlings and young stands. As long as older plantations are thinned on a regular cycle of 10-15 years, tree growth and vigor is generally maintained and tree mortality and/or growth loss due to insect infestations is minimal.

Insect Feeding Groups

Good general references on insects associated with red pine are Wilson (1977), Goulding and others (1988), and Rose and others (1999). These references provide information on identification, insect biology, and some management recommendations.

Needle Feeding Insects

Red pine does not have a single, major defoliator that undergoes regional outbreaks. However, there are defoliators that undergo localized outbreaks, causing growth loss and on occasion, tree mortality. Redheaded pine sawfly, *Neodiprion lecontei,* is the most likely species to cause significant damage. Pine tussock moth, *Dasychira plagiata,* can also kill trees. Both of these species eat both old (previous years) and current year needles, completely defoliating trees. Red pine, like most conifers, will die following complete defoliation. Most other defoliators found on red pine eat either old or current year needles.

Early spring feeders

Both red pine sawfly, *Neodiprion nanulus nanulus,* and European pine sawfly, *Neodiprion sertifer* feed prior to new needle expansion. Only needles from previous years are eaten and therefore, damage is minimal. The European pine sawfly is an exotic species that is limited to warmer parts of the region, specifically the southern half of Wisconsin, southern one-third of Minnesota, and the Lower Peninsula of Michigan.

Late spring feeders

Jack pine budworm, *Choristoneura pinus pinus,* will feed on newly emerging red pine needles (Kulman and Hodson 1961). Red pine growing in close association with jack pine are most likely to be infested. Outbreaks are cyclic, occurring every 7-11 years. In red pine, growth loss and top-kill can occur.

Pine tussock moth has infrequent outbreaks that have been generally restricted to northwestern Wisconsin (Sreenivasam et al. 1972). Tree mortality has been reported following outbreaks.

Summer feeders

Redheaded pine sawfly outbreaks have occurred throughout the Lake States. Heavy feeding is more prevalent on young trees (< 20 ft tall), and on sites that would be defined as stressful for red pine. These sites include highly disturbed sandy areas, frost pockets, and hardwood edges. An extensive review of redheaded pine sawfly ecology and management is available (Wilson et al. 1992).

Pine webworm*, Tetralopha robustella,* forms conspicuous nests of excrement held together with silk. Though commonly encountered in young plantations in the Great Lakes region, large outbreaks have not been reported.

Late summer/Fall feeders

Feeding by the red-pine needle midge, *Thecodiplosis piniresinosae,* occurs throughout the summer, but the characteristic needle browning does not develop until late fall. In early summer, midge larvae tunnel into the base of needle fascicles. Feeding causes premature needle mortality referred to as fall browning or needle droop. Damage is often concentrated in the tops of young trees where terminal mortality can occur. Persistent midge populations have been associated with plantations growing on poor quality red pine sites (Kearby and Benjamin 1964). Outbreaks have been reported in parts of central and western Wisconsin.

Sapsucking Insects

Sapsucking insects can reduce tree health or vigor by removing large quantities of sap. But, what is more important, their feeding often creates wounds that eventually plug and permanently reduce sap flow through twigs and branches. Wound sites can also serve as entry points for pathogens. Sapsucking insects include aphids, adelgids and spittlebugs.

Saratoga spittlebug, *Aphrophora saratogensis,* has probably been the most significant pest of young red pine across northern portions of Michigan, Minnesota and Wisconsin. Reports of damage have not been widespread the past 10-20 years, but outbreaks were prevalent in the 1950s through the early 1980s. Adult Saratoga spittlebugs insert their straw-like mouthparts into red pine shoots and large spittlebug populations cause extensive wounding that can kill branches. Tree mortality can occur and plantation failures have been reported. High populations are associated with abundant sweetfern, the plant that serves as a host for the immature stage of the spittlebug. Planting red pine into areas with sweetfern creates a high risk of spittlebug attack. Several other plants can also serve as an alternate host including willows and raspberries/blackberries. An extensive review of Saratoga spittlebug ecology and management is available (Wilson 1987).

Root and Root-Collar Insects

Several insects feed on the roots and in the root collar region of red pine. On occasion, some of these have been significant pests. This includes white grubs (Coleoptera: Scarabaeidae), and several weevil (Coleoptera: Curculionidae) species.

White grubs are the immature stage of beetles referred to as May and June beetles. There are several different species of white grubs that can feed on pine roots. Larvae live in the soil and feed on fine roots of many plants, including young pine. They have been responsible for planting failures throughout the Lake States region. Most damage has occurred when planting into existing sod. Fowler and Wilson (1971) recommended against planting in fields with populations as low as 0.25 larvae per square foot of sod.

Three weevil species (*Hylobius radicis, H. pales*, and *Pachylobius picivorus*) were reported to be closely associated with the decline syndrome referred to as red pine pocket decline (Klepzig et al. 1991). These insects along with a couple of bark beetle species (*Ips pini* and *Dendroctonus valens*) appear to play a role in introducing root invading fungi that initiate expanding pockets of mortality in plantations.

Pine root collar weevil, *Hylobius radicis,* can be a serious pest of young (5-15 year old) red pine. Larvae feed at the base of trees where they can girdle trees or cause stem deformity. Heavily infested trees often break at the damaged site and tip over. Damage is associated with poorly stocked stands growing in heavy grass. Windbreak trees and trees growing along the edges of plantations are most likely to be infested. Scotch pine, *Pinus sylvestris*, is very susceptible to this weevil and red pine growing in association with Scotch pine is more likely to become infested. An extensive review of root collar weevil ecology and management is available (Wilson and Millers 1983).

The root tip weevil, *Hylobius rhizophagus*, is most often found attacking red pine growing in close association with jack pine (Kearby and Benjamin 1969). Jack pine is regarded as the main host for this weevil. Infested red pines have flagged (dead) branches and often appear stunted. The symptoms can be very similar to Saratoga spittlebug attacks or some of the shoot pathogens. Proof of root tip weevil attack consists of finding larvae or root damage. This weevil does not attack at the root collar, but feeds on the outer portions of the root systems.

Shoot- and Tip-Mining Insects

Shoot and tip-mining insects are not tree killers, however they can cause damage by affecting tree form and growth rates. Over most of the range of red pine in the Great Lakes region, this group of insects would not be considered a major concern. However, there are two moth species that do cause considerable damage in some areas. The European pine shoot moth, *Rhyacionia buoliana* occurs in warmer parts of Lower Michigan and the southeastern portions of Wisconsin. The red pine shoot moth, *Dioryctria resinosella,* is prevalent in areas dominated by outwash sands, such as the Central Sands of Wisconsin. A potential new tip-mining pest of red pine is the pine shoot beetle, *Tomicus piniperda*, an exotic bark beetle that has a shoot mining stage. This species is discussed below in the section on bark and wood infesting insects. The white pine weevil, *Pissodes strobi,* has been reported attacking red pine (Graham and Satterlund 1956), but this is not common.

European pine shoot moth was considered a pest in Lower Michigan beginning in the 1950s (Miller 1967). Larvae feed on buds and shoots. The worst damage occurs when heavy infestation causes the top whorl to lose dominance to a branch on the lower stem. Damage tends to be corrected over time. Distribution of this insect is limited by its inability to survive cold winter weather. It can be found in Lower Michigan, southeastern Wisconsin, and a few other locations where consistently heavy snow cover provides insulation for winter survival of larvae. This shoot moth is not viewed as a viable pest over most of the range of red pine in the Upper Peninsula, Minnesota or Wisconsin.

Red pine shoot moth was initially identified as a significant pest in the 1980s in the Central Sands region of Wisconsin. Larval shoot feeding resulted in height growth losses of 38-65% and radial growth losses of 16-42% over a 9-year epidemic period (Hainze and Benjamin 1984). Following outbreaks, tree crowns changed from straight-stemmed and conical to a bushy and flat-topped appearance. In some plantations, tree form has been altered enough to make it difficult to develop products such as utility poles and cabin logs. Katovich and Hall (1992) provide further information on this insect.

Bark and Wood Infesting Insects

Pine bark beetles in the genus *Ips* are found in association with almost every red pine that dies. They are generally viewed as secondary pests. That means that in most cases they cannot successfully infest and kill a healthy, vigorous tree. Rather they need a tree that is weakened and unable to defend itself. Bark beetles kill trees by attacking in mass. Healthy red pine trees can defend themselves by producing pitch or resin. Trees stressed by drought, old age, fire injury, root disease or intense competition (dense plantations) produce little resin and become susceptible to attack. The exception to this rule would be when very large beetle populations are produced and mass attacks occur at such high numbers that even a healthy tree may be killed.

Red pine is attacked by several species of *Ips* in the region. The most common is the pine engraver, *Ips pini*. Other species include *Ips grandicollis,* and *Ips perroti*. In general, *Ips* attacks rarely occur in plantations younger than 25 years of age. Past that point, outbreaks are often associated with lack of thinning and drought. In most situations, outbreaks are limited to small groups (3-5) of trees. However, during periods of significant drought, several acres of trees can be killed. Logging operations can also trigger local outbreaks. Freshly cut logs left in the woods in the spring and early summer provide breeding material that produces large beetle populations. Population increases of 10-fold can occur in one growing season, with three generations of *Ips pini* possible. Thus, a local population of 1,000 can increase to 1,000,000 individuals in one season. A single downed tree could produce as many as 80,000 beetles (Ayres et al. 1999).

The red turpentine beetle, *Dendroctonus valens*, is a common bark beetle found attacking at the base of trees. Attacks occur from the ground-line up about 3-4 feet. Characteristic popcorn-like pitch tubes are diagnostic. These beetles are not considered tree killers but their tunnels and feeding further reduces tree vigor making infested trees susceptible to infestation by *Ips* bark beetles.

Ips bark beetles along with the red turpentine beetle and several weevil species have been reported to be closely associated with the decline syndrome referred to as red pine pocket decline (Klepzig et al. 1991).

A potential new bark beetle pest is the exotic pine shoot beetle, *Tomicus piniperda.* This European bark beetle lays its eggs and develops under the bark of recently killed and stressed pines much like our native *Ips* beetles. However, the adults also have a feeding stage inside the shoots of their host trees. High populations can result in heavy shoot mining and the loss of significant amounts of foliage. Red pine is a suitable host for pine shoot beetle (Siegert and McCullough 2001). But, to date, the presence of Scotch pine has always been closely linked with outbreaks in North America. Siegert and McCullough (2001) reported that *T. piniperda* were more likely to colonize Scotch pine than red pine. Pine shoot beetles are present throughout Lower Michigan and the eastern Upper Peninsula.

Seed and Cone Insects

Red pine has an array of insects that attack its reproductive structures, especially developing second year cones (Mattson 1978). These insects can cause complete crop failures and be a significant detriment to natural regeneration efforts. The most significant insect pest of red pine cones is the red pine cone beetle, *Conophthorus resinosa.* Mattson (1980) reported that over an 11-year period, the red pine cone beetle destroyed 79% of the annual cone crops in a study area in northern Wisconsin. The population of cone beetles is controlled largely by the size of the annual cone crops. Cone beetle populations collapse to low levels during crop failures. Therefore, damage levels can be quite low in years following crop failures. The greatest chance for significant damage follows several years of high cone production. Red pine cone beetles spend the winter on the forest floor in hollowed-out shoots. This habit makes them susceptible to ground fires. Miller (1978) showed that a prescribed fire done prior to beetle emergence in the spring could control cone beetles in red pine seed production areas.

Insects and Stand Development

Table 1 lists the most commonly encountered insect pests on red pine in the Great Lakes region.

Table 1. Insect pests associated with different stages of red pine plantation development.

Seedlings (1-5 years)	Saplings (6-20 years)	Pole-sized (21-40 years)	Mature and Old-growth (41-200 + years)
White grubs	Saratoga spittlebug	*Ips* bark beetles	*Ips* bark beetles
Saratoga spittlebug	Root collar weevil	Root tip weevil	Red turpentine beetle
	European pine shoot moth	Red pine shoot moth	Red pine shoot moth
	Redheaded pine sawfly	Pine shoot beetle	Pine shoot beetle
	Red pine sawfly	Jack pine budworm	Jack pine budworm
	European pine sawfly	Red pine needle midge	Red pine cone beetle
	Pine tussock moth	Pine tussock moth	
	Pine webworm	Red pine cone beetle	

Newly Planted Seedlings (Age 1-5)

Seedlings have very small root systems that can be easily damaged by root feeding insects. In the Great Lakes region, white grubs are a common problem (Fowler and Wilson 1971), especially when seedlings have been planted into existing sod.

Sapling Stands (Prior to crown closure)

In some situations, insect caused damage in young plantations can be extensive. Cases of plantation failure have been reported, most often due to infestations of Saratoga spittlebug on sites dominated by sweetfern. Many of these sites have also been frost pockets.

Root collar weevil can also be a serious pest of young red pine, often on nutrient-deficient sites. Poorly planted trees with j-roots are very susceptible as are trees growing in heavy sod. Scotch pine is a favored host of this weevil and its presence may increase the likelihood of attack.

Defoliators are an infrequent problem, but outbreaks of redheaded pine sawfly or pine tussock moth can kill young trees. Localized outbreaks of redheaded pine sawfly are most often associated with either dry nutrient poor sites or mesic nutrient rich sites. Nutrient rich sites often develop excessive competition for young red pine.

Shoot-mining insects do occur in young red pine stands but, they would be considered relatively minor pests. European pine shoot moth damages the terminal bud and can cause distorted growth. However, it does not occur over most of the range of red pine in the Lake States. Red pine shoot moth attacks can begin in plantations prior to crown-closure but, most outbreaks have been reported in slightly older stands. On rare occasions, white pine weevil will attack the terminals of red pine.

Pole-sized Stands (After crown closure)

Following crown closure, red pine stands are relatively immune to most insect related problems. Bark beetles in the genus *Ips* would be one damaging agent that can kill small groups of 1-10 trees. On rare occasions, areas as large 1-10 acres may be killed. *Ips* bark beetles attack trees that are weakened by poor site conditions, drought or intense competition. Thinning stands as recommended in existing red pine management guides should reduce competition stress and decrease the likelihood of *Ips* infestations.

In areas dominated by outwash sands the red pine shoot moth can be a considerable pest in plantations that are 20-40 years of age. Growth loss and the loss of apical dominance can occur following prolonged outbreaks. If local outbreaks do occur, managers may need to adjust for a loss of tree form, thus eliminating the opportunity to develop certain products such as utility poles.

Pockets of declining and dead trees can occur in red pine plantations. Bark beetles and several weevil species have been shown to carry pathogens that can initiate decline in red pine trees that may develop into a slowly expanding pocket of dead and dying trees (Klepzig et al. 1991).

In some areas, the root tip weevil can kill pole-sized pine outright. Root tip weevil is most prevalent in northwestern and central Wisconsin and the western half of the Upper Peninsula. The presence of jack pine intermixed with red pine increases the likelihood of infestations.

Defoliation events in middle-aged red pine stands are uncommon. Jack pine budworm can be a local concern in red pine growing in close association with jack pine. Needle midges have caused localized areas of needle browning in late fall.

Mature and Old Growth Trees

Red pine are capable of a very long life span. Dead and dying trees do become infested with *Ips* bark beetles and other wood boring insects but, it is unclear if they are acting as a primary killing agent or if they are using a host that is dying from other causes. Older red pine appear to be capable of maintaining the ability to defend themselves against insects and pathogens. One study conducted at Itasca State Park in Minnesota found mature red pine trees (100-220 years old) to have higher resin flow than younger trees on similar sites (Ayres et al. 1999). The authors concluded that old-age trees at Itasca Park were not senescing and were not poorly defended against bark beetles. Any insect attacks such as defoliation or tunneling under the bark, would add stress and could make old trees more susceptible to other insects as well as several pathogens.

Steps to Avoid Insect Related Problems

Most insect related problems in red pine are associated with certain site and stand conditions. By knowing what these conditions are, many problems can be avoided.

Site Selection and Planting

Planting red pine onto appropriate sites will significantly reduce the likelihood of insect attacks. Use ecological classification systems such as habitat type guides to identify sites appropriate for red pine management.

Do not plant into heavy grass competition. Grass can be an intense competitor with young trees and white grub populations can be high in existing sod. If possible, control grass with herbicides or some other form of site preparation prior to planting. Also, survey grassy sites for grubs before planting.

Do not plant into areas dominated by sweetfern. Incidence of Saratoga spittlebug is directly related to abundance of sweetfern. Use the guides found in Wilson (1987) to evaluate the site for risk to Saratoga spittlebug. If the site is already planted, eliminate the sweetfern.

Do not plant red pine into frost pockets. Recurring frost stunts growth and reduces tree vigor making trees mores susceptible to insect injury. Saratoga spittlebug damage is often concentrated in frost pockets.

Healthy, well planted seedlings will develop fast growing young trees that should be better able to withstand insect feeding than would poor quality, poorly planted seedlings.

Developing diversity within plantations is generally viewed as a positive step in forest health. However, red pine should not be mixed with Scotch pine under any circumstances. Jack pine can also share pest insects with red pine, including jack pine budworm, pine tussock moth and root tip weevil. White pine and some hardwoods would be appropriate associates on many sites.

Established Plantations

Thin red pine stands as recommended in existing red pine management guides. High stand density can create competition stress making trees more susceptible to bark beetles.

During spring and summer thinning operations, remove cut material larger than 4 inches within three weeks. Winter harvested material should be removed before warm spring weather occurs.

Thinning should be done during late summer, fall or winter.

Remove any Scotch pine that is intermixed with red pine.

Literature Cited

Ayers, M. P., M. J. Lombardero, B. D. Ayres, and A. E. Santoro. 1999. *The biology and management of bark beetles in old growth forests of Itasca State Park.* Colfax, WI: Great Lakes Institute for Pine Ecosystem Research.

Benzie, J. W. 1977. *Manager's Handbook for red pine in the North Central States*. USDA Forest Service, Gen Tech. Rep. NC-33.

Eyre, F. H., and P. Zehngraff. 1948. *Red pine management in Minnesota*. USDA Forest Service, Circular no. 778.

Fowler, R. F., and L. F. Wilson. 1971. White grub populations, *Phyllophaga* spp., in relation to damaged red pine seedlings in Michigan and Wisconsin plantations (Coleoptera: Scarabaeidae). *Michigan Entomologist* 4:23-28.

Goulding, H. A., D. J. Hall, K. F. Raffa, and A. J. Martin. 1988. *Wisconsin woodlands: identifying and managing pine pests in Wisconsin.* University of Wisconsin-Extension, Publication G3428.

Graham, S. A., and D. R. Satterlund. 1956. White pine weevil attacking red pine. *Journal of Forestry* 54:133-134.

Haack, B., and D. Kucera. 1993. *New introduction–common pine shoot beetle, Tomicus piniperda (L.)* USDA Forest Service, Northeastern Area, NA-TP-05-93.

Hainze, J. H., and D. M. Benjamin. 1984. Impact of the red pine shoot moth, *Dioryctria resinosella* (Lepidoptera: Pyralidae), on height and radial growth in Wisconsin red pine plantations. *Journal of Economic Entomology* 77:36-42.

Katovich, S. A., and D. J. Hall. 1992. How to identify and minimize red pine shoot moth damage. USDA Forest Service, Northeastern Area, NA-FR-01-92.

Kearby, W. H., and D. M. Benjamin. 1964. The biology and ecology of the red-pine needle midge and its role in fall browning of red-pine foliage. *Canadian Entomologist* 96:1313-1322.

Klepzig, K. D., K. F. Raffa, and E. B. Smalley. 1991. Association of an insect-fungal complex with red pine decline in Wisconsin. *Forest Science* 37:1119-1139.

Kulman, H. M., and A. C. Hodson. 1961. The jack-pine budworm as a pest of other conifers with special reference to red pine. *Journal of Economic Entomology* 54:1221-1224.

Mattson, W. J. 1978. The role of insects in the dynamics of cone production of red pine. *Oecologia* 33:327-349.

Mattson, W. J. 1980. Cone resources and the ecology of the red pine cone beetle, *Conophthorus resinosae* (Coleoptera: Scolytidae). *Annals Entomological Society of America* 73:390-396.

Miller, W. E. 1967. The European pine shoot moth–ecology and control in the Lake States. *Forest Science Monograph* 14:1-72.

Miller, W. E. 1978. Use of prescribed burning in seed production areas to control red pine cone beetle. *Environmental Entomologist* 7:698-702.

Rose, A. H., O. H. Lindquist, and K. L. Nystrom. 1999. *Insects of eastern pines*. Natural Resources Canada, Canadian Forest Service, Publication 1313.

Siegert, N. W., and D. G. McCullough. 2001. Preference of *Tomicus piniperda* (Coleoptera: Scolytidae) parent adults and shoot-feeding progeny adults for three pine species. *Canadian Entomologist* 133:343-353.

Sreenivasam, D. D., D. M. Benjamin, and D. D. Walgenbach. 1972. *The bionomics of the pine tussock moth*. University of Wisconsin-Madison, School of Natural Resources, Research Bulletin 282.

Wilson, L. F. 1977. *A guide to insect injury of conifers in the Lake States.* USDA Forest Service, Agriculture Handbook 501.

Wilson, L. F. 1987. *Saratoga spittlebug—its ecology and management.* USDA Forest Service, Agriculture Handbook 657.

Wilson, L. F., and I. Millers. 1983. *Pine root collar weevil—its ecology and management.* USDA Forest Service, Technical Bulletin No. 1675.

Wilson, L. F., R. C. Wilkinson, and R. C. Averill. 1992. *Redheaded pine sawfly—its ecology and management.* USDA Forest Service, Agriculture Handbook 694.

Disease Considerations in Red Pine Management

M. E. Ostry, Research Plant Pathologist, USDA Forest Service,
North Central Research Station, 1561 Lindig Ave. St. Paul, MN 55108,
651-649-5113, mostry@fs.fed.us.,
J. O'Brien, Plant Pathologist, USDA Forest Service,
Forest Health Protection, 1992 Folwell Ave. St. Paul, MN 55108, 651-649-5266,
and
M. Albers, Forest Health Specialist, Minnesota Department of Natural Resources,
1201 E. Hwy #2, Grand Rapids, MN 55744, 218-327-4234[1]

ABSTRACT. Red pine (*Pinus resinosa*) was relatively free of serious damaging diseases prior to 1960. Since that time several pathogens have become major problems in managing healthy red pine in some areas. A number of factors may be responsible for increased damage caused by these pathogens. Many of the diseases have developed both directly and indirectly from past nursery and forest management practices and from various environmental stress factors. Genetic uniformity and lack of disease resistance in red pine has contributed to widespread incidence and severity of disease outbreaks. Perhaps one of the most important factors in the increase of some disease problems in red pine has been the unintentional shipment and planting of infected nursery stock.

KEY WORDS. *Pinus resinosa*, shoot blights, cankers, nursery stock, pathogens, epidemiology

Introduction

During European settlement, harvest of white pine, followed by red pine together with destructive fires over the extensive cutover areas, rapidly depleted the merchantable pine by the early 1900s. Today red pine grows only on a fraction of its historic range across the Lake States. Because of its wide range of use in commercial products and its potential use for aesthetic and ecological restoration, red pine could be grown on suitable sites on many more acres than it is.

Reforestation in the Lake States was greatly accelerated in the 1930's under the Civilian Conservation Corps when red pine was widely planted, resulting in plantations that today are vastly different from presettlement forests where red pine grew in largely mixed species stands.

[1] Ostry, M. E., J. O'Brien, and M. Albers. 2002. Disease considerations in red pine management. In *Proceedings of the Red Pine SAF Region V Technical Conference*, eds., Gilmore, D. W., and L. S. Yount, 107-111. Staff Paper no. 157. St. Paul, MN: University of Minnesota, College of Natural Resources, Department of Forest Resources.

In the 1950s it became apparent that diseases were beginning to impact red pine survival and productivity in plantations and nurseries and, by the early 1960s, several serious diseases developed requiring their consideration in red pine management.

Many of the important red pine diseases in the Lake States region have developed either directly or indirectly as a result of past logging, nursery management and reforestation practices (Ostry 2000). Several factors have contributed to these disease outbreaks. Tree stress on degraded sites, "off site" plantings, red pine monocultures or greatly reduced species diversity increased the risk for disease in plantations. The lack of genetic diversity for disease resistance in red pine has resulted in disease outbreaks where all of the trees are damaged. In addition, the inadvertent planting of infected nursery stock; the invasion and establishment of exotic pathogens and possibly fire exclusion have contributed to the spread and establishment of some pathogens. Many of the diseases that have become damaging are diseases of seedlings and young trees that are more susceptible to mortality than are older trees.

Major Red Pine Diseases

Brief descriptions of the most damaging diseases and the biology of the causal pathogens including guidelines to minimize their impacts in plantations and natural stands are provided in the following sections. Collectively, these pathogens can cause greater damage than any of them acting alone. In many areas of the Lake States the co-occurrence of these pathogens and insect pests within the same stands, or even on the same trees, makes accurate diagnosis of the damage difficult.

To help managers recognize problems, several illustrated publications have been developed on identifying red pine diseases including descriptions of pathogen life cycles and suggestions for disease management. These are available online at the following websites: http://www.na.fs.us/spfo/ and http://www/ncrs.fs.fed.us/.

Scleroderris Canker

Scleroderris canker, caused by *Gremmeniella abietina*, has caused mortality of young trees in Canada since 1934 (Laflamme 1995) and has been known to cause disease of trees in Michigan since 1950 even though the identity of the pathogen was not determined until 1964 (Skilling et al. 1986). Its incidence increased markedly with the planting of large areas of red pine in the last 40 years.

The disease is most damaging to young trees and develops on infected lower branches under snow cover. The incidence and severity of the disease is generally highest in frost pockets and in areas that receive deep snows. Planting trees in field sites favorable for disease development and movement and planting of infected nursery stock resulted in this disease becoming a major problem in the Lake States and Northeastern States.

There are two strains of the fungus in North America. The North American strain produces two spore stages and infects trees only within the lower crowns, killing small trees. The European strain has only one known spore stage but can infect trees high in the crowns and kill trees of all ages. The European strain has not been found in the Lake States.

Prevention of Scleroderris canker begins with planting healthy seedlings and avoiding planting red pine in frost-pocket depressions and near infected trees. Pruning the lower branches of infected and healthy young trees may also minimize damage.

Sphaeropsis Shoot Blight and Canker

Sphaeropsis sapinea causes serious shoot blight and cankers. Severe epidemics have developed on trees stressed by drought or injured and predisposed to infection by other adverse environmental conditions. The fungus readily infects trees through succulent shoot tissues, branch stubs, or wounds caused by logging, pruning, hail, and insects. Stem cankers on red pine caused by the fungus were first reported in Minnesota and Wisconsin in 1976 (Nicholls and Ostry 1990).

Seedlings growing near infected red pines in nursery windbreaks are susceptible to infection unless preventive fungicides are applied. In addition, trees in nurseries and the field may be infected but exhibit no disease symptoms until they become stressed. This may account for the sudden and widespread disease outbreaks that periodically occur (Stanosz et al. 1997). Rapid mortality of red pine seedlings and saplings associated with Sphaeropsis collar rot (Stanosz and Cummings Carlson 1996) has been widespread and most likely the result of planting asymptomatic seedlings that were infected in the nursery.

Minimizing damage by Sphaeropsis shoot blight and canker begins by planting seedlings from nurseries known to prevent disease through cultural and chemical treatments. Red pine should not be planted next to or under infected red pine because under the right environmental conditions they can become infected by inoculum from diseased branches, needles, and cones (Palmer et al. 1988).

Attempts to regenerate red pine using seed tree or shelterwood methods where the disease is present should be avoided. If natural regeneration is desired, the red pine overstory should be removed after the stand has achieved sufficient advanced regeneration to stock the stand. Since *S. sapinea* is most damaging on stressed trees, plant red pine on good sites and maintain high tree vigor through competition control.

Sirococcus Shoot Blight

A shoot blight caused by the fungus *Sirococcus conigenus* was first detected in Wisconsin red pine in 1959 (O’Brien 1973) and became epidemic in many plantations throughout the Lake States in the mid-1970s. Similar to Sphaeropsis shoot blight, periodic outbreaks continue to damage and kill young red pine growing under or adjacent to older red pine (Ostry et al. 1990). However, unlike *S. sapinea*, *S. conigenus* only infects new shoot tissues, rarely entering older stem tissues and disease incidence is most severe under wet spring weather conditions.

The current interest in managing uneven-aged stands of red pine has renewed concerns over the impact of this disease. Avoid planting red pine under or adjacent to infected trees. Removing the infected overstory trees and infected shoots on the understory trees before spore dispersal in early spring will reduce the major sources of inoculum and minimize future disease incidence and severity.

Root, Butt, and Trunk Rots

Shoestring root rot caused by species of *Armillaria* is common, and is especially damaging to stressed trees and trees attacked and weakened by insects. Annosus root rot, caused by *Heterobasidion annosum*, has not been a widespread problem in red pine, but it can potentially be damaging after thinning and harvesting.

Inonotus tomentosus causes a butt rot of mature trees and can infect seedlings planted on sites where the fungus is already present. *Phellinus pini* causes a trunk rot of mature trees sometimes called red rot. The fungus invades trees through wounds and dead branches and causes a white pocket rot.

Maintaining high stand vigor, avoiding planting red pine on known infested sites where root diseases previously have been damaging, and avoiding wounding trees during stand entries may minimize damage by root and wood decaying fungi.

Needle Diseases

Needle diseases affect red pine and can be periodically severe, depending on site, weather, and the interactions of insect pests and other predisposing factors. Needle diseases such as Lophodermium needlecast caused by *Lophodermium seditiosum* and needle rust caused by *Coleosporium asterum* are seldom damaging except in nurseries and Christmas tree plantations, but at times can be conspicuous.

Conclusions

Several pathogens with the potential to kill young red pine or reduce tree growth are established in the Lake States. Managers should consider the impacts of these pathogens before planting and continue to monitor plantings for their presence after stand establishment. Strategies for minimizing damage caused by these pathogens begin with site selection and continue throughout the rotation of the planting. There are few practical direct disease management options for plantations. Instead, proper planning, use of disease-free planting stock, timely application of silvicultural treatments to maintain high tree vigor, early detection of both insect and disease problems, and utilizing an integrated approach to management of pest complexes will increase the success of red pine management.

Literature Cited

Laflamme, G. 1995. The earliest report of Scleroderris canker in North America. In *Proceedings Shoot and Foliage Diseases in Forest Trees*, eds., Capretti, P., U. Heiniger, and R. Stephan, 210-213. Istituto di Patologia e Zoologia Forestale e Agraria, Universta degli Studi di Firenze, 309 p.

Nicholls, T. H., and M. E. Ostry. 1990. *Sphaeropsis sapinea* cankers on stressed red and jack pines in Minnesota and Wisconsin. *Plant Dis*. 74:54-56.

O'Brien, J. T. 1973. Sirococcus shoot Blight of red pine. *Plant Dis. Reptr*. 57:246-247.

Ostry, M. E. 2000. How do diseases affect forest ecosystem restoration? In *Proceedings of Forest Ecosystem Restoration: Ecological and Economical Impacts of Restoration Processes in Secondary Coniferous Forests*, ed., Hasenauer, H., 200-205. Vienna, Austria: Institute of Forest Growth Research, University of Agricultural Sciences. 418 p.

Ostry, M. E., T. H. Nicholls, and D. D. Skilling. 1990. Biology and control of Sirococcus shoot blight on red pine. USDA Forest Service Res. Pap. NC-295. 11 p.

Palmer, M. A., R. E. McRoberts, and T. H. Nicholls. 1988. Sources of inoculum of *Sphaeropsis sapinea* in forest tree nurseries. *Phytopathology* 78:831-835.

Skilling, D. D., B. Schneider, and D. Fasking. 1986. Biology and control of Scleroderris canker in North America. USDA Forest Service Res. Pap. NC-275. 18 p.

Stanosz, G. R., and J. Cummings Carlson. 1996. Association of mortality of recently planted seedlings and established saplings in red pine plantations with Sphaeropsis collar rot. *Plant Dis*. 80:750-753.

Stanosz, G. R., D. R. Smith, M. A. Guthmiller, and J. C. Stanosz. 1997. Persistence of *Sphaeropsis sapinea* on or in asymptomatic shoots of red and jack pines. *Mycologia* 89:525-530.

The Economics of Red Pine Management in the Lake States

Michael Kilgore and Katherine Martin[1]
Assistant Professor and Research Assistant, respectively,
Department of Forest Resources, College of Natural Resources, University of Minnesota,
St. Paul, MN 55108, 612-624-6298. mkilgore@umn.edu

ABSTRACT: Over the past fifteen years, red pine pulpwood and sawtimber prices have increased substantially in the Lake States. After adjusting for inflation, all three states experienced real annual stumpage price increases during the period 1985-2000 that were above their long-term historical average, as well as those projected for the region through 2050. Establishing red pine stands typically consists of site preparation, planting, and site release. Although reforestation costs vary considerably among public land managers in Minnesota, Michigan, and Wisconsin, investing $400 per acre to establish red pine is common. An examination of USDA-Forest Service's Forest Inventory and Analysis (FIA) data reveals similar red pine age-class and yield relationships among the three states. This data indicates current per acre productivity is substantially below its potential as suggested by previous red pine productivity research. Investing in red pine management to capture tree mortality through periodic thinning can significantly increase per acre productivity and financial performance, as well as create stand conditions associated with important ecological benefits and amenity values.

KEY WORDS: Economics, forest management, productivity

Introduction

Red pine is arguably the most extensively studied tree species in the Lake States. Seminal studies on red pine management (Buckman 1962; Lundgren 1981; Gervorkiantz 1957; Wambach 1967) provide a foundation of understanding regarding red pine growth and productivity. Several studies have also examined the economic performance of red pine management (Bradley and Lothner 1984; Liechty et al. 1988; Lundgren 1965). In light of recent trends in red pine stumpage prices, this paper examines opportunities for investing in red pine management in the Lake States. Data on the extent and condition of the Lake States' red pine resource, stumpage prices, and establishment and management costs were assembled to assist in evaluating these opportunities.

---

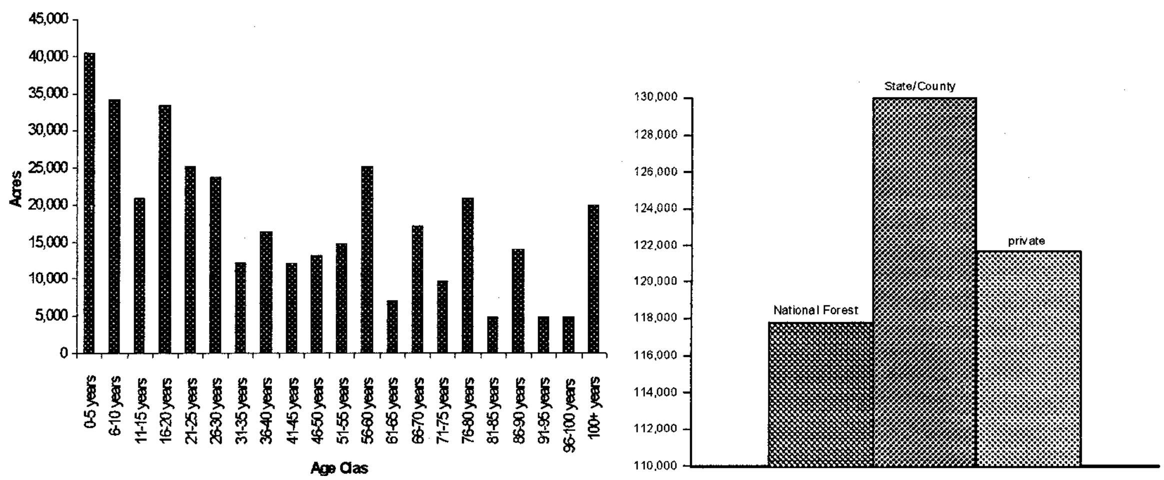
[1] Kilgore, M., and K. Martin. 2002. The economics of red pine management in the Lake States. In *Proceedings of the Red Pine SAF Region V Technical Conference*, eds., Gilmore, D. W., and L. S. Yount, 112-123. Staff Paper no. 157. St. Paul, MN: University of Minnesota, College of Natural Resources, Department of Forest Resources.

Characteristics of the Lake States Red Pine Covertype

The extent of the red pine covertype in the Lake States has increased more than fivefold over the past 70 years to its current area of 1.875 million acres (Schmidt 2002). Using the most recent data from the USDA-Forest Service's Forest Inventory and Analysis (FIA) database reveals important information about the current condition of the Lake States' red pine resource.

Minnesota

Minnesota has approximately 375,000 acres of the red pine covertype (Figure 1). The age class distribution of red pine is moderately even, with all five year age classes through age 100 being represented. Half the state's red pine covertype is less than 35 years old, and several of the five year classes between 60 and 100 years contain less than 5,000 acres. The ownership of Minnesota's red pine resource is relatively evenly distributed between state and local governments (130,000 acres) and federal resource management agencies (117,800 acres). Private forests account for approximately 122,000 acres of the state's red pine resource.



Source: USDA: Forest Service, Forest Inventory and Analysis.

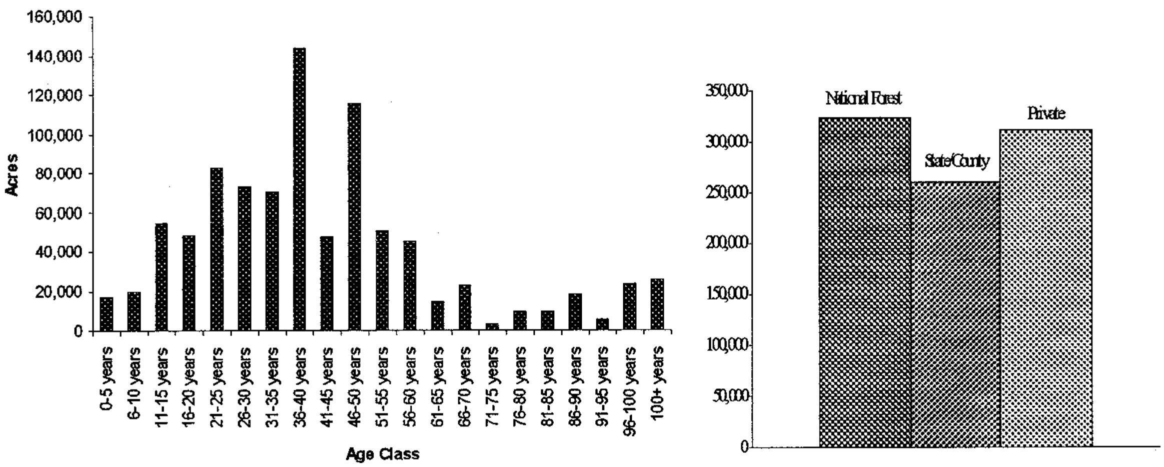
Figure 1. Age class and ownership distribution of Minnesota's red pine covertype.

Michigan

Michigan contains approximately 900,000 acres of red pine—the largest amount of the three Lake States and over twice the amount found in Minnesota (Figure 2). Examination of the age class distribution reveals most of the state's red pine is moderately young—85 percent of the red pine covertype is between 11 and 70 years old. Only 10 percent of the red pine acreage is older than 70 years old, and 5 percent is in a regeneration stage (less than 10 years old). The federal government owns 36 percent of the red pine resource in Michigan, making it the state's single largest owner. Private forest landowners hold slightly less acreage (311,000 acres or 35 percent of Michigan's red pine resource), and state and local governments account for the state's remaining 29 percent (259,000 acres) of the red pine covertype.

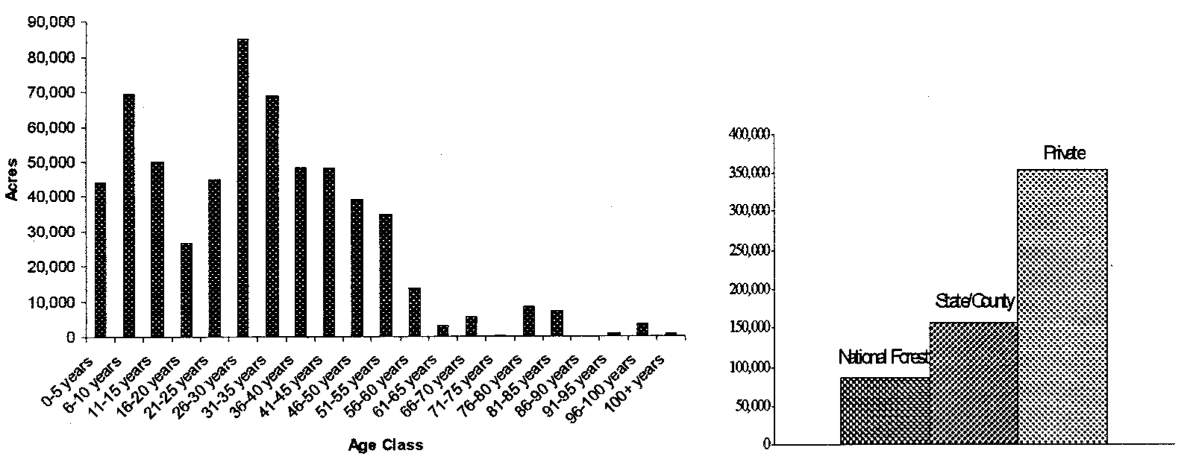
Wisconsin

Wisconsin has approximately 600,000 acres of the red pine covertype (Figure 3). Like Michigan, Wisconsin's red pine resource is young. More than 96 percent is 70 years or younger. In fact, the state has less than 1,000 acres of the red pine covertype older than 100 years. This is in contrast to Minnesota and Michigan, both of which have more than 20,000 acres of red pine 100 years or older. Also in contrast to Michigan and Minnesota, Wisconsin's red pine is predominantly owned by private landowners, which collectively hold 59 percent (353,000 acres) of the state's total red pine covertype. State and local governments in Wisconsin collectively manages 26 percent (156,000 acres), and the federal government holds 16 percent (94,000 acres) of the red pine covertype.



Source: USDA: Forest Service, Forest Inventory and Analysis.

Figure 2. Age class and ownership distribution of Michigan's red pine covertype.



Source: USDA: Forest Service, Forest Inventory and Analysis.

Figure 3. Age class and ownership distribution of Wisconsin's red pine covertype.

Growing Stock Volume

FIA data in all three states was examined to determine growing stock volume per acre across the distribution of red pine age classes (Figure 4). Data in all states suggest a similar pattern, namely a leveling off or decline in growing stock volume/acre after age 40 for a period of 20-30 years. In Minnesota, this trend is least pronounced whereas growing stock volume per acre exhibit pronounced declines in Michigan and Wisconsin for the red pine covertype between 40 and 65 years of age. The fitted line in Figure 4 depicts this pattern of growing stock volume for red pine across age classes. The reasons for this pattern are unclear, but possible explanations include:

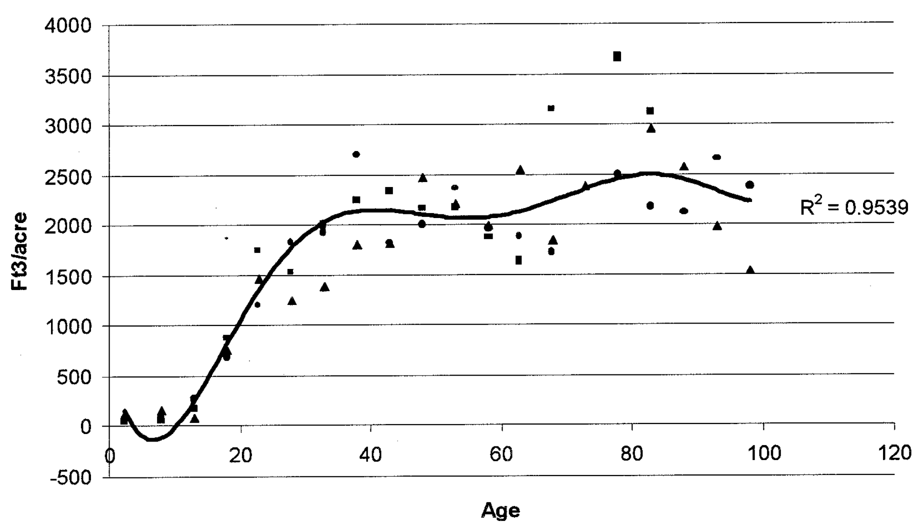
- Widespread thinning of red pine stands during in these age classes, thereby reducing total standing volume in intermediate stand ages.

- Decreasing average stand site quality with increasing stand age. Examination of average site index for red pine stands in the FIA database indicates a gradual decline in site index with increasing covertype age exists in all three Lake States.

- Covertype reclassification in the FIA database as the stand develops due to changing relative volumes of tree species present in the stand.

- A limited number of FIA plots in older red pine stands, which may not be reflective of typical stand conditions for that age class.

- Varying site quality of red pine plantations over time. FIA surveys represent a point-in-time estimate of average stand conditions and, as such, should not be interpreted as a stand growth curve.



Source: USDA-Forest Service, Forest Inventory and Analysis.

Figure 4. Red Pine Growing Stock Volume Per Acre in the Lake States.

Stumpage Price Trends

Pulpwood

Lake States red pine pulpwood and sawtimber stumpage prices were assembled for the period 1985-2000 using data provided by the Minnesota and Wisconsin DNR and Michigan State University. In 1985, red pine pulpwood prices were less than $15 per cord in all three states (Table 1). Wisconsin had the highest pulpwood prices at $14.49 per cord, while Minnesota and Michigan's red pine pulpwood prices were $9.28 and $6.39 per cord, respectively. Over the period between 1985 and 2000, Lake States pulpwood prices experienced annual increases that ranged from 4.75 (Minnesota) and 14.61 percent (Michigan), with Wisconsin's pulpwood prices rising an averaging 7.60 percent annually. In 2000, Michigan's red pine pulpwood prices approached $50 per cord ($49.45). Wisconsin's red pine pulpwood prices averaged $43.47 per cord, while Minnesota had red pine pulpwood selling for less than half the price ($18.61 per cord) found in Wisconsin and Michigan.

Table 1. Average Nominal Red Pine Pulpwood Prices ($ per cord).

	1985	1986	1987	1988	1989	1990	1991	1992
MN[a]	$ 9.28	7.97	7.34	7.48	14.79	13.04	14.06	8.14
MI[b]	$ 6.39	6.44	7.89	9.89	11.06	11.56	13.40	17.77
WI[c]	$ 14.49	15.28	14.3	14.77	13.14	13.36	14.01	14.22

	1993	1994	1995	1996	1997	1998	1999	2000
MN[a]	$ 10.39	24.57	17.49	21.18	23.35	15.63	17.02	18.61
MI[b]	$ 20.10	29.42	31.14	30.09	32.87	36.92	40.44	49.45
WI[c]	$ 15.97	19.13	27.45	26.35	27.08	30.25	36.58	43.47

[a] Data provided by the Minnesota Department of Natural Resources and represents average prices received for stumpage sold by public land management agencies in Minnesota.
[b] Data provided by Michigan State University's Eastern Hardwood Utilization Project and represents average prices received for stumpage sold by the MI Department of Natural Resources.
[c] Data provided by Wisconsin Department of Natural Resources and represents average prices received for stumpage sold by private, state, and county forest sales (1985-1987) and state and county forest sales (1988-2000).

Nominal red pine pulpwood stumpage prices were deflated to assess real stumpage price changes between 1985 and 2000. The consumer price index was used as a measure of inflation as it best reflects the impact of inflation on nonindustrial private forest owners (the largest owner of private forest land in the Lake States). During the period 1985 to 2000, real (inflation adjusted) red pine pulpwood prices increased in all three states. The range of this increase varied considerably from 10.99 percent annual increase in Michigan to 1.44 percent annual increase in Minnesota. Wisconsin saw real red pine pulpwood increase an average of 4.2 percent over this 15-year period.

Sawtimber

Table 2 indicates prices received for red pine sawtimber in the Lake States between 1985 and 2000. In 1985, sawtimber prices ranged from just more than $50 per mbf in Wisconsin to nearly $78 per mbf in Michigan. By 2000, red pine sawtimber prices ranged from $136.12 per mbf in Wisconsin to nearly $225 per mbf in Michigan, while Minnesota's red pine sawtimber price was $176 per mbf. Over this 15-year period that ended in 2000, nominal sawtimber prices for red pine rose between 6.83 (Wisconsin) and 7.33 (Michigan) percent annually. Unlike pulpwood prices, percent increases in sawtimber price were relatively uniform across the three states.

After adjusting for inflation, sawtimber prices for red pine increased in excess of 3 percent per year in all three states between 1985 and 2000. The rate at which real sawtimber price increased was fairly uniform among the three states, ranging from 3.45 percent per year in Wisconsin to 3.94 percent per year in Michigan. Minnesota's red pine sawtimber prices rose an average of 3.78 percent per year between 1985 and 2000.

Table 2. Average nominal red pine sawtimber prices ($ per mbf).

	1985	1986	1987	1988	1989	1990	1991	1992
MN[a]	$ 62.34	52.95	57.7	66.85	88.9	93.55	101.13	108.84
MI[b]	$ 77.72	71.91	74.22	76.23	86.55	80.65	100.19	93.41
WI[c]	$ 50.53	54.37	68.00	59.15	62.98	70.19	67.37	69.06

	1993	1994	1995	1996	1997	1998	1999	2000
MN[a]	$ 132.83	183.95	171.55	163.64	174.34	161.01	198.99	176.01
MI[b]	$ 109.17	172.24	184.64	180.43	191.35	230.68	207.35	224.69
WI[c]	$ 75.23	94.63	96.13	105.74	96.59	120.84	125.26	136.12

[a] Data provided by the Minnesota Department of Natural Resources and represents average prices received for stumpage sold by public land management agencies in Minnesota.

[b] Data provided by Michigan State University's Eastern Hardwood Utilization Project and represents average prices received for stumpage sold by the MI Department of Natural Resources.

[c] Data provided by Wisconsin Department of Natural Resources and represents average prices received for stumpage sold by private, state, and county forest sales (1985-1987) and state and county forest sales (1988-2000).

Comparing Recent Stumpage Trends to Long Term Averages

Data from the draft RPA Timber Assessment was used to contrast how the recent red pine stumpage price increases in the Lake States compare to long-term stumpage price trends. Between 1952 and 1997, real softwood stumpage prices in the northern United States experienced an average annual increase of 0.34 percent for pulpwood and 0.43 percent for sawtimber (Haynes 2002). This suggests that the recent (1985-2000) real price increases in the Lake States for both red pine pulpwood and sawtimber are substantially above long-term historical stumpage price increases. Additionally, they are considerably higher than the long term stumpage real prices projections through the mid point of this century, suggesting the recent run up in red pine stumpage prices cannot be sustained into the future. For the northern United States, average annual real stumpage prices are projected to increase 0.44 percent for sawtimber and 0.63 percent for pulpwood between 1997 and 2050.

Stand Establishment Costs

Public forest management agencies in the Lake States were contacted to provide information on current red pine reforestation practices and associated costs. Red pine reforestation practices were categorized as site preparation, planting, and post planting activities. Table 3 indicates the types of practices commonly employed in the Lake States, a range in costs as well as an estimate of an average cost associated with each practice. All costs are in dollars per acre. In the Lake States, per acre start-to-finish red pine reforestation costs range from $200 to $500, with $400 per acre being a typical expenditure to establish red pine stands.

Table 3. Red pine regeneration practices and associated costs in the Lake States.

	$ per acre	
ACTIVITY	**Range**	**Typical**
Site Preparation		
Disk Trenching	$ 60 - 135	$ 80
Roller Chop	90 - 160	120
Brush Rake	100 - 350	200
Burning	40 - 80	60
Planting		
Hand Planting	40 – 120	75
Mechanical Planting	90 – 350	150
Bare Root Stock	75 – 100	80
2-0 Container	100 – 150	120
Seeding	75 - 110	100
Post Planting		
Herbicide Release	30 – 165	70
Regeneration Surveys	5 - 15	10
Start-To-Finish Reforestation	$ 200 - 500	$ 400

Current Economic Performance

Using current red pine productivity, stumpage prices, and management costs in the Lake States, returns to red pine management were estimated by calculating land (soil) expectation values (LEV). Important assumptions used in making these estimates are inflation-adjusted stumpage prices increasing an average of 0.5 percent per year and a real discount rate of 3 percent. Table 4 indicates that land expectation values associated with red pine management range from $366 to $864 per acre. Major sources of the variation in land expectation values between states are stumpage price and productivity differences.

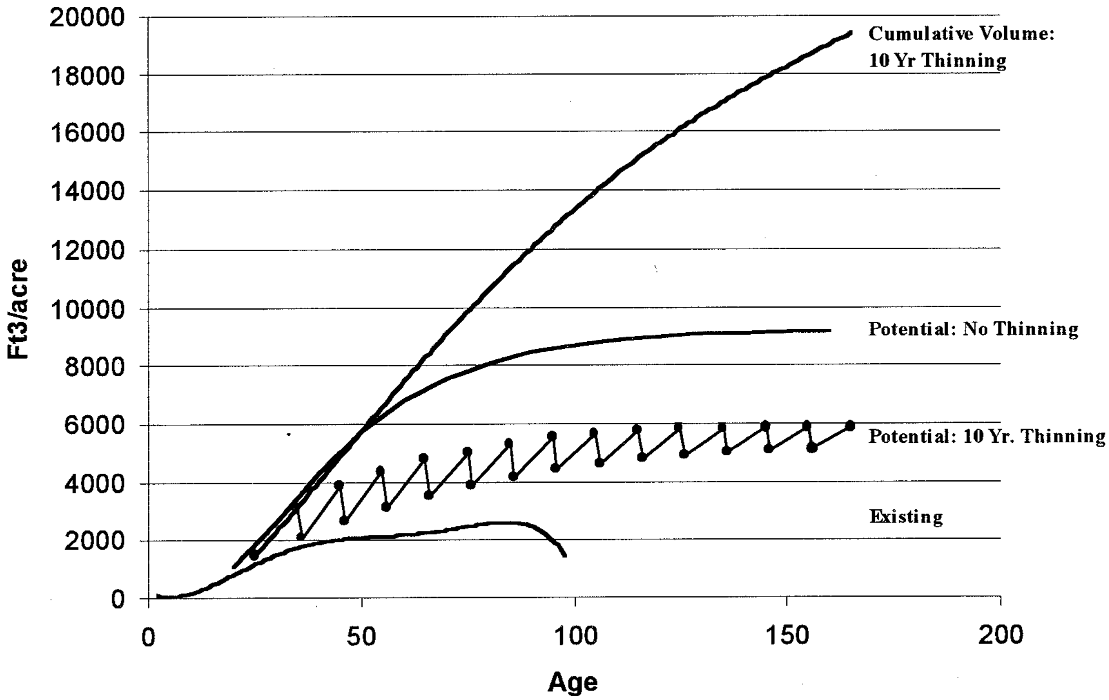
Table 4. Land expectation values and internal rates of return: Existing red pine productivity in the Lake States.

	Land Expectation Values ($ per acre)	Internal Rate of Return (real)
Minnesota	$448	4.2 %
Michigan	$864	5.2 %
Wisconsin	$366	4.4 %

Productivity Potential: Economic and Ecological Implications

Stand Yield

How does the current red pine productivity in the Lake States compare to its potential as documented by previous field studies on red pine growth and yield? To answer this question, data on red pine growth and yield associated with fully stock unthinned (Lundgren 1981) stands and stands subject to commercial thinning beginning at age 35 and continuing at 10 year intervals (Buckman 1962) were analyzed to assess potential economic performance. Figure 5 indicates the yields associated with these two management alternatives, as well as current red pine growing stock volume in the Lake States as suggested by the most recent FIA data. Note that under a 10 year thinning regime, cumulative stand volume approaches 20,000 ft^3 per acre—approximately twice the total volume yield from unthinned stands.



Sources: USDA-Forest Service, Buckman (1962), and Lundgren (1981).

Figure 5. Existing and potential red pine yields.

Financial Performance

Using average red pine stumpage prices and management cost data for the Lake States, land expectation values and rates of return are estimated for fully stocked thinned and unthinned red pine stands (Table 5). With an assumed 3 percent real discount rate and 0.5 percent real annual increase in red pine stumpage prices, land expectation values are estimated to be just less than $1,600 per acre for stands subject to 10 year thinning and $1,923 per acre for unthinned stands. Internal rates of return are 5.4 percent for thinned and 6 percent for unthinned red pine stands.

Table 5. Land expectation values and internal rates of return to red pine management.

	Land Expectation Value ($ per acre)	Internal Rate of Return
10 Yr. Thinnings	$ 1,594	5.4 %
No Thinnings	$ 1,923	6.0 %

A key factor in determining the financial performance of red pine investments is the real growth in stumpage price. When no real changes in stumpage prices are assumed over time, LEVs decline to $941 per acre for thinned stands and $1,206 per acre for unthinned stands

(Table 6). This represents a 41 percent and 37 percent reduction in LEVs for these two stand management alternatives, respectively, when contrasted to LEV estimates that incorporate a 0.5 percent annual real price increase. When stand establishment costs are reduced by 50%, LEVs increase only 14 percent ($1,819 per acre) for thinned stands and 13 percent ($2,182 per acre) for unthinned stands over their baseline LEVs. When no real stumpage price increases are assumed, red pine stands incurring no establishment costs are still approximately $200 below their baseline value, suggesting future returns to red pine management are much more sensitive to future real stumpage price increase than the cost of stand establishment.

Table 6. Sensitivity to real stumpage price changes and stand establishment costs.

	Land Expectation Value (% departure from baseline LEV)
No Real Price Increase	
10 Yr. Thinnings	$ 941 (-41%)
No Thinnings	$ 1,206 (-37%)
50% Decrease in Establishment Costs	
10 Yr. Thinnings	$ 1,819 (+14%)
No Thinnings	$ 2,182 (+13%)

Productivity Gains and Ecological Implications

While investing in red pine management can improve the stand's financial performance, investments to increase productivity can also produce important ecological benefits (e.g., wildlife habitat and other amenity values associated with old red pine forests). Further, intensifying management means fewer acres will be required to produce a given volume of wood fiber. Figure 6 illustrates the number of acres required to produce an equivalent 100,000 cords of red pine based on the existing productivity of red pine in the Lake States, as well as what could potentially be grown under more intensive management regimes. With an assumed rotation age of 85 years, stands periodically thinned require only 700 acres to produce 100,000 cords—nearly one-fourth the total required under current management intensity. By intensifying management to increase forest productivity, public resource managers have greater flexibility in accommodating other important forest resource values and uses.

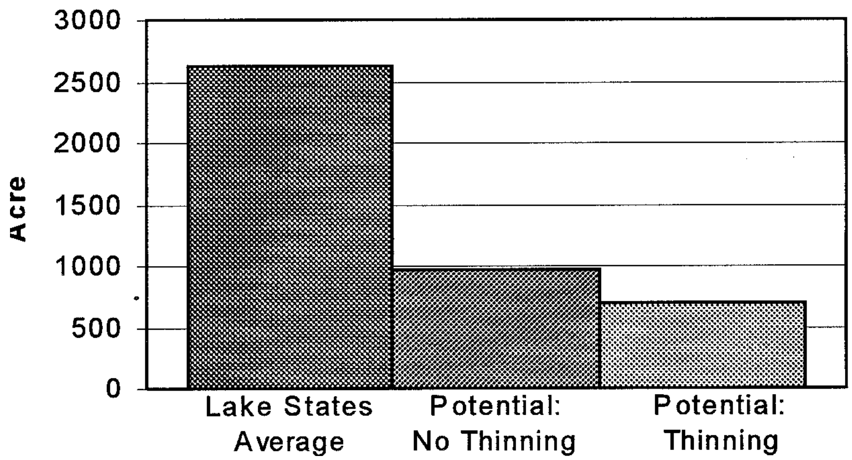


Figure 6. Number of acres needed to produce 100,000 cords of red pine (85 yr. rotation).

Conclusions

Recent red pine stumpage price increases in the Lake States have renewed interest in the management of this important tree species. By maintaining full stand stocking and employing periodically thinning, landowners can substantially increase per acre productivity and financial returns to management. Whether the rates of return associated with these strategies are high enough to attract significant private sector investment in red pine management in the Lake States is uncertain. Real red pine stumpage price increases will be a key determinant in the financial performance of these investments.

Literature Cited

Bradley, D. P., and D. C. Lothner. 1984. A New Look at Red Pine Financial Returns in the Lake States. USDA Forest Service Research Paper NC-246.

Buckman, R.E. 1962. Growth and Yield of Red Pine in Minnesota. USDA Forest Service Technical Bulletin 1272.

Gervorkiantz, S. R., and L. P. Olson. 1955. Composite Volume Tables for Timber and Their Application in the Lake States. USDA Technical Bulletin 1104.

Haynes, R. 2002. An Analysis of the Timber Situation in the United States: 1952 to 2050. A Technical Document Supporting the 2000 USDA Forest Service RPA Assessment (draft). Portland, OR: USDA-Forest Service, Pacific Northwest Research Station.

Liechty, H. O., D. D. Reed, and G. D. Mroz. 1988. An interim economic comparison of thinning treatments in a high site quality red pine plantation. *Northern Journal of Applied Forestry* 5:211-215.

Lundgren, A. L. 1965. Thinning Red Pine for High Investment Returns. USDA Forest Service Research Paper LS-18.

Lundgren, A. L. 1981. The Effect of Initial Number of Trees Per Acre and Thinning Densities on Timber Yields From Red Pine Plantations in the Lake States. USDA Forest Service Research Paper NC-193.

Schmidt, T. L. 2002. Red pine in the northern Lake States. Presented at the Red Pine Management SAF Region V Technical Conference. March 26-27, 2002. Cloquet, MN: Cloquet Forestry Center, University of Minnesota.

Wambach, R. F. 1967. A Silvicultural and Economic Appraisal of Initial Spacing in Red Pine. Ph.D. Thesis. St. Paul, MN: Department of Forest Resources, University of Minnesota.

Red Pine Utilization and Markets

Jim L. Bowyer[1], Director, Forest Products Management Development Institute,
Department of Wood and Paper Science, University of Minnesota,
St. Paul, MN 55108, Tel. (612) 624-4292, Fax (612) 625-6286,
jbowyer@umn.edu

ABSTRACT. Red pine occurs over a broad geographic range, stretching from southern Canada and the north central United States to Nova Scotia and New England. Extensive areas of plantations, most of which were established from the late 1930s to the mid-1950s, exist across the region, with significant acreage in the Lake States. Many of these stands will need to be thinned if the best trees within them are to achieve the maximum potential size and growth. However, a lack of markets for red pine, and particularly for small diameter trees, is limiting silvicultural options.

An examination of red pine properties show it to be a premiere species among medium density pines of the U.S. and Canada. It is at the top of the list with respect to strength properties, and in this regard compares well to radiata pine, a highly promoted species internationally. In addition, red pine exhibits a number of other properties that are comparable to those of better known species in national and international markets.

One potential for expanding red pine markets may be to actively promote the species. Currently, red pine attributes are minimally publicized, while wood with which it competes in domestic and international markets are backed by technical support and actively promoted.

A new emphasis nationwide on utilization of small diameter trees is gaining considerable momentum, and a major national conference focused on economic uses for "smallwood" was held in early April, 2002. One example of a new innovation for using small diameter trees is the ISO-beam (or inside-out beam); this technology allows structural use of wood from small diameter trees while reducing potential negative effects of juvenile wood.

KEY WORDS: Forest products, wood properties, markets, small diameter.

---

[1] Bowyer, J. L. 2002. Red pine utilization and markets. In *Proceedings of the Red Pine SAF Region V Technical Conference*, eds., Gilmore, D. W., and L. S. Yount, 124-130. Staff Paper no. 157. St. Paul, MN: University of Minnesota, College of Natural Resources, Department of Forest Resources.

Introduction

Red pine (*Pinus resinosa* L.), also known as Norway pine, covers a large area of the northern U.S. and southern Canada. The species extends in the U.S. from northern Minnesota eastward through Wisconsin, Michigan, northern Pennsylvania, south-central and eastern New York, Vermont, New Hampshire, and Maine. In Canada, the range encompasses Ontario, Quebec, New Brunswick, and Nova Scotia. Scattered patches of red pine also occur south of the primary range along the Appalachian mountains.

Extensive areas of plantations, most of which were established from the late 1930s to the mid-1950s, exist across the entire region in which red pine occurs naturally, with significant acreage in Minnesota, Wisconsin, and Michigan. Many of these stands will need to be thinned if the best trees within them are to achieve the maximum potential size and growth. However, a lack of markets for red pine, and particularly for small diameter trees, is limiting silvicultural options for treating these stands.

Red Pine Properties

Strength

Red pine has superior properties to many species that are better known in domestic and international markets. For example, a comparison of key strength properties of red pine with properties of ponderosa and lodgepole pine, balsam fir, and white spruce (Table 1) shows red pine to have superior properties in every respect. Red pine also compares well with radiata pine, a species that is aggressively promoted and traded in international markets.

Table 1. Strength properties of red pine compared to other species.

Species		Specific gravity	MOE $(lb/in^2) \times 10^6$	MOR (lb/in^2)	Impact bending (in)	Comp. ll to grain (lb/in^2)	Shear ll to grain (lb/in^2)	Side hardness (lb)
Red pine	Green	0.41	1.28	5,800	26	2,730	690	340
	12% MC	0.46	1.63	11,000	26	6,070	1,210	560
Ponderosa	Green	0.38	1.00	5,100	21	2,450	700	320
pine	12% MC	0.40	1.29	9,400	19	5,320	1,130	460
Lodgepole	Green	0.38	1.08	5,500	20	2,610	680	330
pine	12% MC	0.41	1.34	9,400	20	5,370	880	480
Balsam fir	Green	0.33	1.25	5,500	16	2,630	662	290
	12% MC	0.35	1.45	9,200	20	5,280	944	400
White	Green	0.33	1.14	5,000	22	2,350	640	320
spruce	12% MC	0.36	1.43	9,400	20	5,180	970	480
Radiata	Green	0.42	1.18	6,100		2,790	750	480
pine	12% MC	0.48	1.48	11,700	22	6,080	1,600	750

Source: USDA-Forest Service, Wood Handbook, 1999.

It should be noted that red pine is not in the same league as a structural timber as southern yellow pine, Douglas fir, or western larch; these woods possess exceptional strength and are widely used in applications where very high strength is needed. However, red pine sits essentially at the top of the list of second-tier species with respect to strength.

Suitability for Use with Timber Connectors

As a wood for use with timber connectors, such as those used in construction to tie beams and columns together, red pine is again as good or better than many commonly used construction woods, but less desirable than southern pine, Douglas fir, or western larch (Table 2). Although radiata pine does not appear in Table 2, it is likely a Group 3 wood, since suitability for use with connectors is largely determined by compression strength perpendicular to the grain.

Table 2. Red pine use with connectors compared to other species.

Connector	Species or species group		
	aspen	basswood	cottonwood
Group 1	western red cedar	balsam fir	white fir
	eastern hemlock	eastern white pine	ponderosa pine
	sugar pine	western white pine	Engelmann spruce
	chestnut	yellow poplar	baldcypress
Group 2	yellow cedar	Port Orford cedar	western hemlock
	red pine	redwood	red spruce
	Sitka spruce	white spruce	
	American elm	slippery elm	soft maple
Group 3	sweetgum	sycamore	tupelo
	Douglas-fir	western larch	southern pine
	white ash	beech	birch
Group 4	rock elm	hickory	hard maple
	oak		

Source: USDA-Forest Service, Wood Handbook, 1999.

Dimensional Stability

The dimensional stability of red pine with moisture content change is very similar to many other better know species (Table 3). Red pine is not as dimensionally stable as ponderosa pine, but is far better in this regard than southern yellow pine or western larch.

Table 3. Red pine dimensional stability compared to other species.

Species	Radial	Tangential	Volumetric
Red pine	3.8	7.2	11.3
Ponderosa pine	3.9	6.2	9.7
Lodgepole pine	4.3	6.7	11.1
White spruce	3.8	7.8	11.8
Balsam fir	2.9	6.9	11.2
Radiata pine	3.0	7.0	11.1

Source: USDA-Forest Service, Wood Handbook, 1999.

Other Properties

In several other respects, including machining properties and ease of heartwood treatment with preservative chemicals, red pine is on a par with a number of better known species (Tables 4 and 5). In addition, red pine is classed as moderately durable for uses in which wood is not in ground contact, is known to hold nails and screws well, and is relatively easy to dry.

Table 4. Red pine machining index in comparison to other species.

Ease of Machining	
Species	**Index**
Red pine	64
Ponderosa pine	65
White fir	51
Eastern white pine	62
Yellow poplar	68
Radiata pine	70

Source: New Zealand Forest Research Institute as reported in Evergreen Forests Ltd. (2002).

Table 5. Red pine preservative penetration of heartwood compared to other species.

Ease of Penetration		
Least difficult	ponderosa pine	radiata pine
Moderately difficult	jack pine southern yellow pine	red pine eastern white pine
Difficult	white spruce	

Source: USDA-Forest Service, Wood Handbook, 1999.

Properties Summarized

In summary, red pine is a premiere species for many applications. It performs particularly well from a strength standpoint, but has many other desirable properties as well that compare quite favorably to other woods that are more widely used domestically and internationally.

More Aggressive Promotion - One Strategy for Increasing Market Demand

It is revealing to search for information on various woods on the Interet. Using the words "radiata pine" or "radiata pine and strength properties" in a search engine such as *Yahoo* yields numerous sites that provide technical data and promotional information.[2] Ditto for ponderosa and lodgepole pine. All three species are promoted by strong industry associations. When the same search is performed for red or Norway pine the results are far different. While it is possible to readily find information on red pine silviculture, there is little information about the properties of red pine and virtually nothing in the way of promotional material. Moreover, there is no industry association that either promotes the species or that provides technical support to buyers. Thus, one strategy for increasing markets for red pine could be to expand promotional activities. Use of web sites, promotional literature, and perhaps an association of manufacturers might be employed.

The Small Diameter Problem

How to profitably use small diameter trees that are harvested in thinning operations has long been an issue in forestry. Today, this issue is moving to center stage as concerns grow about very high fuel loads in the publicly owned forests of the western U.S. resulting from decades

[2] See: www.austehc.unimelb.edu.au/tia/210.html; http://www.ronayne.co.nz/pine/; www.atesscoinc.com/RadiataPine/default.asp; arborresources.co.nz; www.insights.co.nz/sustainable_plantations_wrp.asp; www.evergreen.co.nz/reports/futurewood.pdf; www.timspec.co.nz/radiata.html/

of fire suppression and low levels of harvest. A broad consensus is emerging that thinning of softwood forests is needed on a massive scale in order to restore these forests to fuel loading that more closely resemble natural conditions. It is also increasingly apparent that developing markets for small diameter logs is essential to financing restoration activities.

Highlighted by Dr. Peter Koch in his three-part series "Lodgepole Pine in North America" (Koch 1996), the need for large-scale utilization of small diameter trees is now recognized by researchers across North America, and a number of research organizations and entrepreneurs have begun to concentrate on this problem. A major national conference focused on economic uses for "smallwood" will be held in Arizona in early April 2002.

One example of a new innovation for using small diameter trees is the ISO-beam (Patterson 1998, Patterson and Kluender 2000). These are made by squaring and then quartering small logs, and then reassembling the pieces such that the outer surfaces of the log wind up in the core of the beam (Figure 1). The resulting beam has radial surfaces all-around, giving the benefits of edge-grain lumber, and the tendency for deep checking due to tangential vs. radial shrinkage.

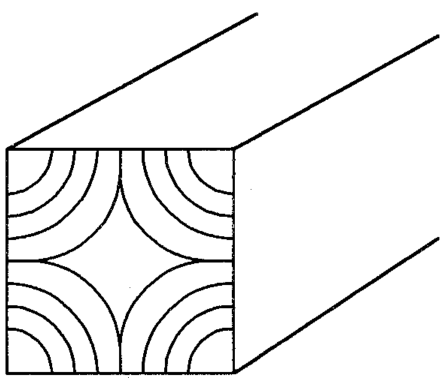


Figure 1. Representation of an ISO-Beam.

Summary

Red pine occurs over a wide geographic area, with significant volumes in plantations that were established 50 to 70 years ago. There is currently a need to thin these plantations in order to maximize growth and diameter prior to final harvest, and development of markets for small diameter logs is key to financing a thinning effort.

In domestic and international markets red pine is not as well known as other species with which it competes despite the fact that red pine has superior properties to many of these species. Part of the answer to finding markets for small diameter red pine may lie in better promotion of red pine in general.

The use of small diameter material has become a major research thrust nationally in the last several years in response to the fire threat in the western U.S. Many new ideas are surfacing as to how to economically use such material, with the ISO-beam being one example. ISO-beams are made by squaring and then quartering small logs, and then reassembling the pieces such that the outer surfaces of the log wind up in the core of the beam. The end-product has high strength without the problems common to solid products that incorporate the heart-center of logs.

Literature Cited

Evergreen Forests Ltd. 2002. *Radiata Pine - the Future Wood*. http://www.evergreen.co.nz/reports/futurewood.pdf

Koch, P. 1996. *Lodgepole pine in North America*. Vol. 1-3. Madison, WI: Forest Products Society.

Patterson, D. W. 1998. Inside-out beams from small diameter Appalachian hardwood logs. *Forest Products Journal* 48(1):76-80.

Patterson, D. W., and R. A. Kluender. 2000. The technical and economic feasibility of producing inside-out beams from small diameter logs. In *Issues related to handling the influx of small-diameter timber in western North America*, ed. Gazo, R. Proceedings, Forest Products Society, 1999 National Annual Meeting, Boise, ID.

USDA-Forest Service. 1999. *Wood Handbook - Wood as an Engineering Material*. Forest Products Laboratory General Technical Report FPL-GTR-113.

The Chapman Plantation at the University of Minnesota, North Central Research and Outreach Center, Grand Rapids, Minnesota

Timothy C. O'Brien, Research Plot Coordinator, Department of Forest Resources,
University of Minnesota, North Central Research and Outreach Center,
Grand Rapids, MN, tobrien@umn.edu ; and
Keith Matson, Forestry Technician, Marcell/Deer River Ranger District,
Chippewa National Forest and Minnesota SAF History Committee chair[1]

Forestry Beginnings

Perhaps the beginnings of forestry in Minnesota can be traced to the establishment of the Minnesota State Forestry Association on January 11, 1876. N. H. Winchell was studying the geology and natural history of Minnesota, traveling the state in the 1890s. In 1893, 1894, and 1897 during his study of Carlton County he was assisted by Horace B. Ayres, who was in the employ of the Division of Forestry, in the U.S. Department of Agriculture. Ayres also assisted Professor Samuel B. Green in his writing of "*Forestry in Minnesota,*" the first forestry publication within Minnesota. Although there was no school of forestry, the Horticultural Department awarded a degree in forestry to Herman Haupt Chapman in 1899, the first such degree awarded by the University of Minnesota. Chapman had earned a Bachelor of Science degree from the University in 1896, and later took all the instruction being offered in forestry to earn his second degree as a Bachelor of Agriculture.

In 1896 Chapman had been working at the Minnesota experimental farm at the University, and a year later was appointed the superintendent of the state's Northeastern Agricultural Experiment Farm at Grand Rapids. While at Grand Rapids, Chapman became an advocate for establishment of a national forest reserve in the headwaters of the Mississippi River between Cass Lake and Grand Rapids. This effort was to assist in the creation of the Minnesota National Forest Reserve in 1902, the first such forest reserve to be created by an act of Congress. Gifford Pinchot, then Forester in the Bureau of Forestry, had taken personal interest in this area, and Chapman would become a member of the Bureau, conducting studies throughout the nation. In 1901 Chapman enrolled in the Yale School of Forestry in pursuit of his Master of Forestry degree, which he obtained in 1904 after several absences to pursue tasks for Pinchot and the Bureau. In 1906 he began his career as a teacher of forestry at Yale.

---

[1] O'Brien, T. C., and K. Matson. 2002. The Chapman Plantation at the University of Minnesota, North Central Research and Outreach Center, Grand Rapids, Minnesota. In *Proceedings of the Red Pine SAF Region V Technical Conference*, eds., Gilmore, D. W., and L. S. Yount, 131-135. Staff Paper no. 157. St. Paul, MN: University of Minnesota, College of Natural Resources, Department of Forest Resources.

Chapman had been born on October 8, 1874 in Cambridge, Massachusetts, his career at Yale, in New Haven, Connecticut, was a homecoming for him. He also served the Society of American Foresters as vice-president in 1922 and 1923, and president from 1934 to 1937. He had also been director of the American Forestry Association and served on the Connecticut Park and Forest Commission from 1913 to 1947. His efforts led to several changes in SAF including the creation of accreditation for forestry schools and the membership structure requiring members to be graduates of forestry schools (Buell 1963).

North Central Research and Outreach Center

The North Central Experiment Station (NCES), now known as the North Central Research and Outreach Center (NCROC), was established in 1896 as a branch station of the University of Minnesota. Its purpose was to conduct research in agricultural and forestry problems unique to north central and northeastern Minnesota. Today research at NCROC involves many disciplines including agricultural engineering, agronomy, wild rice research, animal sciences, horticulture, and forestry.

Forestry at North Central Experiment Station

"Forestry research was initiated as early as 1897 when W. Pendergast, NCES superintendent at that time, obtained several thousand red pine (*Pinus resinosa*) and jack pine (*Pinus banksiana*) seedlings. The seedlings were forest pulled, wild seedlings received from H.B. Ayres of Carlton. At the same time, Scotch pine (*Pinus sylvestris*) and in 1898 white pine (*Pinus strobus*) were obtained from the USDA Forest Service. These seedlings were placed in a transplant nursery and cultivated to keep them reasonably free from weeds" (Allison 1947).

> "H.H. Chapman became superintendent at N.C.E.S. in 1897 and decided to use the planting stock to set up the earliest forestry research plantation in Minnesota. His plan was to test (1) the relative value for planting purposes of red, white, jack and Scotch pine; (2) the advisability of planting in pure or mixed stands; and (3) the best spacing techniques to use" (Allison 1947).
>
> "In the fall of 1899, Chapman set aside 32 acres of fairly level cut-over land located on the station as an experimental reforestation area and divided it into one acre plots. The surface soil of the tract of land consists of a sandy loam with a subsoil of the same, but coarser and rocky. Soil moisture, determined in 1930 from soil samples, showed a moisture content of 9.2% to 14.6% in the first foot; 10.6% to 14.3% in the second foot; and 7.9% to 14. 3% in the third foot" (Allison 1936).
>
> "In 1900 eight plots were planted to pure stands using the red and white pine. Spacing of 4' by 4', 6' by 6', 8' by 8' and 10' by 10' were set up for each species. Two other plots were set up using 6' by 6' spacing and planted in a Scotch, red pine mixture and a jack, red and white pine mixture. Four more plots of red and white pine were added

to the existing plots in 1901. These consisted of two plots each using 6' by 6' spacing and completed a total of 14 original plots established" (Allison1936).

"Planting was done in late April for both years. Station records indicate that the Scotch pine averaged 17 inches when planted and although there are no records to determine the size of the red, white, and jack pine stock, it is assumed that it was approximately the same size" (Allison 1947).

"The trees were dug from the rows in the nursery with spades and heeled in until needed in the field. When the trees were moved to the field they were thoroughly soaked and placed, roots down, into a wagon box where they remained until needed. From a central location at the site, the trees were distributed to the planters using bushel baskets. All trees were planted with spades. The sod was turned back and enough earth removed to accommodate the roots. A tree was inserted, soil replaced and stomped down and the sod was put back in place" (Allison 1936).

Planting was done by crews of men and boys who received 15 and 5 cents per hour respectively. The boys delivered the trees to the men planting and assisted by holding the trees in place while they were planted. The planting costs were as follows:

"1. The 4' by 4' spacing a total of $11.20/ acre; $7.88 for actual planting and $3.31 for digging and transporting to the site.
2. The 6' by 6' spacing a total of $5.60/ acre; $3.94 for actual planting and $1.66 for digging and transporting to the site.
3. The 8' by 8' spacing a total of $3.14/ acre; $2.22 for actual planting and $.93 for digging and transporting to the site.
4. The 10' by 10' spacing a total of $2.01/ acre; $1.42 for actual planting and $.59 for digging and transporting to the site" (Allison 1936).

"In the spring of 1905, a wildfire swept through the entire plantation. The 4 by 4, 8 by 8 and 10 by 10 foot spaced red and white pine plots were all most completely destroyed. The 6 by 6 foot plots were thinned by the fire, but sufficient stocking remained to make viable plots" (Allison 1947).

Dr. J. H. Allison, University of Minnesota School of Forestry Staff Member, heard of these plots and decided the plantings would be valuable for growth and yield data. Since he was not able to distinguish the original plots or locate a map of the them, he set up his own on what he believed to be the original site. Several years later, an original map was located confirming his location to be part of the original plots. The size and shapes of the plots was determined by the density of the remaining stands after the 1905 fire. These plots varied in size from .25 acres to .57 acres. Of the several plots Dr. Allison originally set up, three plots, approximately .5 acre in size, and consisting of red pine remain today and are referred to as Plots A, B and C (Allison 1936).

Plots A and B has had data collected from it since 1915 and Plot C since 1930. The report pages contain data collected on each plot from 1915 through 1985.

In 1936, Dr. Allison made conclusions concerning the questions pertaining to Chapman's purpose in setting up the original research plots. Addressing each question separately, Dr. Allison's reply to the tests are as follows:

1. What is the relative value for planting purposes of Norway, jack, white and Scotch pines upon sandy soil located in the Grand Rapids region? "The Norway and jack pines are the best trees to plant. Barring rabbit injury one may expect satisfactory survival and subsequent growth of these species except upon areas where there is too much shade. On open areas, to which these plantations were confined, the Norway and jack pines are now as large and distinctly of better form than the white or the Scotch pines. White pine would be an almost equally good tree if it were not for the weeviling of the main trunk leaders which occurred on a large scale between the ages of ten and twenty-five years. The weeviling of this species has resulted in the formation of many crooked and often multiple stemmed trees. While not satisfactory for planting in the open, white pine would probably prove satisfactory for planting under light shade such as might be produced by open stands of birch, popple or other pines. Ordinarily the weevil will not attack white pines growing under light shade. The Scotch pine included in this test has proved distinctly unsatisfactory for forest planting in this region. Although it survives and grows satisfactorily as far as volume is concerned, it is severely attacked by porcupines and sap suckers. These enemies have killed or severely damaged over two thirds of the trees of this species which were healthy fifteen years after planting."

   "Furthermore the undamaged Scotch pine has developed such crooked trunks that they will be practically valueless for saw log purposes. This objection to Scotch pine might be overcome by the use of Finnish, northern Swedish or northern Russian seed. The Scotch pine grown from seed obtained from the more northern part of its European range is a much straighter tree than the Scotch pine grown from seed from the central of southern part of its European range (Germany, Poland, central northern Russia, Etc.)"

2. Is it advisable to mix these species in the establishment of plantations? "It is not advisable to mix white and Norway pine with jack pine unless one is willing and able to go through the plantations at frequent intervals for the purpose of releasing the white or Norway pines by trimming or cutting the jack pines which are overtopping them. During the first twenty years of a plantations life the jack pine grows much faster than either white or Norway pine. In mixed plantations the branches of the jack pine often extend out over the tops of the white and Norway pines, inflicting severe physical damage to the growing tip and the upper branches of these pines. Scotch and Norway pine may be mixed. Both of these species have gotten along satisfactorily with each other in a mixed plantation. In the white Norway pine mixture, the Norway pines are distinctly dominant, but the surviving white pines are

not suffering serious physical injury. Hence there seems to be no serious objection to the use of white and Norway pine in mixture."

3. What spacing should be used in the field planting of these species? "The 1905 fire destroyed practically all of the 4 x 4, 8 x 8, and 10 x 10 foot spacing. Hence the surviving plantations in this series give no answer to this question. Experience here with the 6 x 6 foot spacing indicates that this spacing is a satisfactory one to use, but with the use of this spacing, thinning of the stand should begin by the time it reaches 20 years of age if 75 percent or more of the trees survive" (Allison 1936).

The Chapman Plantation is of great value historically as it is the oldest successful plantation in Minnesota and possibly the United States. The growth and yield data collected may be of even greater value when considering establishment of red pine plantations in the north central United States and the projections that can be made by using the data.

Literature Cited

Allison, J. H. 1936. Original North Central Experiment Station correspondence, dated July 21, 1936.

Allison, J. H. 1947. Forty-Five Year Old Ten Acre Norway Pine Plantation at Grand Rapids Gives Valuable Information. Lake States Timber Digest. November 20, 1947. 16 p., illus.

Buell, J. H. 1963. in *Journal of Forestry* 61(8).

Data sheets compiled from records maintained by the Forestry Department at North Central Experiment Station.

Red Pine SAF Region V Technical Conference

March 26-27, 2002 ***Cloquet Forestry Center***

<u>AGENDA – March 26</u>

Tuesday

8:00 – 8:45 am	Registration, lobby of CFC auditorium
8:45 am	Welcome and Introduction – Louise Yount, UMN; Tom Crow, USFS
9:00 am	Current Inventory – Tom Schmidt, USFS
9:30 am	Guides to Red Pine Management: Where have we been? Where should we go? Al Lundgren, retired, UMN and USFS
10:00 – 10:30 am	Break
10:30 – 11:50 am	Long-term Studies, including Growth and Yield, of Red Pine – Bob Buckman, retired, courtesy faculty Oregon State University
11:50 am	Award presentation
12:00 -1:00 pm	Lunch
1:00 pm	Integrating Biophysical System Products with the Management of Red Pine – Garrett Ous, Itasca Co Land Dept, and Donald Prettyman
1:30 pm	Land Type Associations and their utility for Red Pine Management – Matt Sands, USFS
2:00 pm	Regeneration – Dan Farnsworth, Consulting Forester
2:30 pm	Break
3:00 pm	Multiple species and Multiple Cohorts – Brian Palik, John Zasada, USFS
3:35 pm	Small group discussions *The objective of these two sessions (one each day) is to provide an opportunity for discussion between managers and researchers, which is difficult in the auditorium. This is the time to ask questions about or comment on presentation topics and anything else related to your management of red pine. Please spread yourselves out amongst the 5 rooms.* Auditorium Classroom A/E meeting room Library (upstairs) Conference Room (Management Bldg)
4:15 pm	Report of small group discussion highlights to full conference Additional Q/A as time permits
5:00 pm	Adjourn
Dinner – on your own	
7:00 pm	Evening session for small private landowners: Wildlife and Red Pine. Speaker: Ron Eckstein, WI DNR

Red Pine SAF Region V Technical Conference

March 26-27, 2002 ***Cloquet Forestry Center***

AGENDA – March 27

Wednesday	
8:00 – 8:40 am	Concurrent Sessions C Application of a Stand Density Management Diagram to Red Pine Management – Tom Burk and Tim Mack, UMN. Auditorium. C Integrating Wildlife Habitat in Red Pine Management– Ron Eckstein, WI DNR. Classroom. C 11Year Results of a Red Pine Regional Provenance Test and Options for Converting to a Seedling Seed Orchard – Andy David, UMN. Library.
8:45 – 9:30 am	Concurrent Sessions C Application of a Stand Density Management Diagram to Red Pine Management – Tom Burk and Tim Mack, UMN. Auditorium. C Integrating Wildlife Habitat in Red Pine Management– Ron Eckstein, WI DNR. Classroom. C 11Year Results of a Red Pine Regional Provenance Test and Options for Converting to a Seedling Seed Orchard – Andy David, UMN. Library.
9:30 – 10:00 am	Break
10:00 – 10:40 am	Concurrent Sessions C Utilization and Markets – Jim Bowyer, UMN. Auditorium. C Insects and Pathogens Damaging to Red Pine– Steve Katovich and Mike Ostry, USFS. Classroom. C Economics and Price Trends – Mike Kilgore, UMN. Library.
10:45 – 11:30 am	Concurrent Sessions C Utilization and Markets – Jim Bowyer, UMN. Auditorium. C Insects and Pathogens Damaging to Red Pine – Steve Katovich and Mike Ostry, USFS. Classroom. C Economics and Price Trends – Mike Kilgore, UMN. Library.
11:35 am – 12:15 pm	Small group discussion (Same rooms as March 26)
12:15 pm – 1:00 pm	Lunch
1:00 pm	Report of small group discussion highlights to full conference
1:45 pm	Comments and questions from participants and presenters
2:15 pm	Conclusion and Synthesis of Workshop – Bob Buckman, Al Lundgren, Tom Crow
3:00 pm	Adjourn