A COMPREHENSIVE TREE IMPROVEMENT PLAN FOR MINNESOTA

by

Robert A. Stine, Lawrence K. Miller, Gary Wyckoff, and Bailian Li

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Executive Summary

The comprehensive tree improvement plan provides strategic guidance to tree improvement efforts in Minnesota during the next decade. It addresses applied tree improvement activities, research efforts needed to support those activities, and funding levels. The plan contains five strategic goals.

**Goal 1. Genetic principles should be applied in all forest management decisions in Minnesota.** Forest management activities have a major influence on the genetic composition of both trees in a forest and the associated biota. Thus, the genetic implications of all forest management activities should be considered prior to their application. Tree improvement can assist gene conservation efforts by creation of gene repositories and selective breeding to help maintain or increase the frequency of specific genes or genotypes. Tree improvement programs also help provide options regarding biodiversity. Breeding populations of trees with a broad genetic base provide the opportunity to develop smaller populations with either wide or narrow genetic variation to suit specific needs.

**Goal 2. Genetically improved material should be used to increase productivity of Minnesota's forests.** Genetically improved material can be used in planted stands to increase both productivity and utilization. Such material is typically developed by applied tree improvement programs through a recurring cycle of selection, breeding, and testing. Economic analyses of Minnesota's tree improvement programs consistently yield strong, positive rates of return with benefit-cost ratios ranging up to 17.6.

Seed source control should be practiced by all producers and users of forest reproductive material (seed, seedlings, cuttings, etc.). High-level improvement programs (selection, testing, breeding, seed orchards, etc.) are justified for seven species planted in Minnesota: aspen, white spruce, jack pine, red pine, white pine, red oak, and black walnut. Genetically improved material derived from the high level programs should be used for reforestation purposes as soon after it becomes available as possible. It should be used for direct seeding purposes only when there is surplus beyond all other planting needs.

**Goal 3. Appropriate research should be conducted to support applied tree improvement efforts.** Applied research is needed in several areas to enhance genetic improvement programs. Empirical measures of the impact thinning has on gene frequencies and the growth rates of resulting stands are needed. The genetic impact of various natural regeneration systems on individual species and entire stands also needs study. Such information would permit better choices to be made among natural regeneration options.

More research is needed on regeneration of aspen, red oak, and black walnut. Elements of regeneration which still need study include stock quality, site preparation, and protection from pests (weeds, insects, diseases, animals). A rapid, reliable technique for screening white pine for rust resistance at an early age is needed. More field testing of material with putative rust resistance is also required. Development of a reliable, cost-effective technique to reduce deer browse is needed, and work must continue on techniques for avoiding blister rust and weevil through silvicultural practices. In seed orchards, issues such as soil moisture management, flower induction, pollen enhancement, fertilization, pruning, pollarding, cone and seed insects and diseases, root pruning, influence of micro- and macro-climate, and others all need study.

**Goal 4. Applied tree improvement programs should be appropriately sized to match anticipated needs.** Most applied tree improvement activities in Minnesota fall under the direction of one of three cooperative programs; The Minnesota Tree Improvement Cooperative, the University of Minnesota/Institute of Paper Science and Technology Aspen/Larch Genetics Cooperative, and the North Central Fine Hardwoods Tree Improvement Cooperative. In 1995, 16 different Minnesota organizations were actively participating in
the applied tree improvement efforts of one or more of the cooperatives. Many organizations located outside Minnesota also participate in the three cooperatives and have substantial influence on cooperative activities. Merging the two University of Minnesota-based cooperatives is possible but should be carefully evaluated due to the different focus of each group. At a minimum, communication and cooperation among leaders of the cooperatives should continue and be strengthened in areas such as planning, design, analysis, and other areas that transcend individual species differences.

Genetic improvement plans are provided for nine species: aspen, jack pine, red pine, white pine, black spruce, white spruce, larch, red oak, and black walnut. They provide guidelines for improvement activities over the next decade. During that time, activities should be reviewed to make sure they match the needs of participating organizations, and adjusted accordingly.

From an efficiency standpoint, it is preferable to have a few large seed orchards rather than many small orchards covering the same area. The impact of foreign pollen is reduced in large orchards and operating efficiencies can be realized. To accomplish this, organizations will need to share orchards and reach agreements that allow equitable distribution of both costs and benefits related to establishment and management of the orchards.

Collaboration in applied tree improvement efforts with the national forests in Minnesota needs exploration. There are historical and mandated reasons why the Forest Service has not participated more fully in the cooperatives, but the opportunity may now exist to develop better collaboration. Guidance and encouragement by major forest land owners in the state are needed to accomplish this objective.

**Goal 5.** Tree improvement efforts in Minnesota should be focused, coordinated, and adequately funded. Consensus has arisen that for the next decade, seven species are of equally high priority for improvement efforts in Minnesota. They are aspen, jack pine, red pine, white pine, white spruce, red oak, and black walnut. Because larch is a high priority species outside Minnesota and offers potential value in the state, the Aspen/Larch cooperative will continue high-level tree improvement activities. The level of tree improvement activity that should be devoted to hybrid poplar is unknown at this time.

Cooperative staff members spend a substantial amount of time planning programs, working with organizations in the field, sharing results and information, and communicating with members to make sure that efforts are coordinated. There is little duplication of effort.

Both the private and public sectors fund cooperative tree improvement activities in Minnesota. Total funding to the cooperatives is about $239,000 annually. The sources of funding include legislative appropriations through the University of Minnesota ($155,000), federal and state agencies ($26,000), counties ($22,000), and private industry ($36,000). Distribution of funding among the cooperatives is approximately $182,000 for the Aspen/Larch Cooperative, $57,000 for the Minnesota Tree Improvement Cooperative, and only in-kind support for the Fine Hardwoods Cooperative.

Funding for the Aspen/Larch Cooperative is adequate. Funding for the Minnesota Tree Improvement Cooperative should be increased to support two full-time equivalents (approximately $60,000 additional annually). Direct funding for the Fine Hardwoods Cooperative should be initiated to support one full-time equivalent (approximately $60,000 annually).
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Introduction

The comprehensive tree improvement plan provides strategic guidance to tree improvement efforts in Minnesota during the next decade. It primarily addresses applied tree improvement activities, but because of close interrelationships, the plan also addresses some needed research efforts. It purposely does not provide detailed action plans since they often change based on new information or changing circumstances. However, the plan provides guidelines so the direction of tree improvement efforts in Minnesota is clear.

The plan was developed to provide comprehensive guidance for all activities related to applied tree improvement. Thus, how genetics can be applied in silvicultural activities is discussed, as is development of genetically improved material. Some areas of critically needed research are discussed, and the need for additional funding to support tree improvement efforts is explained.

Drawing on surveys of organizations, written reports, discussions with a variety of individuals, and personal insights, five strategic goals were identified to guide tree improvement activities in Minnesota over the coming decade. They are:

1. Genetic principles should be applied in all forest management decisions in Minnesota.
2. Genetically improved material should be used to increase productivity of Minnesota’s forests.
3. Appropriate research should be conducted to support applied tree improvement efforts.
4. Applied tree improvement programs should be appropriately sized to match anticipated needs.
5. Tree improvement efforts in Minnesota should be focused, coordinated, and adequately funded.

These five strategic goals are discussed in detail below.

Goal 1. Genetic principles should be applied in all forest management decisions in Minnesota.

Minnesota contains about 16.7 million acres of forest land. Most of the forest land is classified as commercial timberland (14.8 million acres), 1.1 million acres are reserved from timber utilization (e.g., state and national parks, wilderness areas, etc.), and another 0.8 million acres are considered unproductive (Jaakko Pöyry Consulting, Inc. 1994:3-4). The genetic makeup of all these forests, both within and among species, is influenced by management activities. In turn, the genetic makeup influences the composition, structure, and outputs of the forest itself. For these reasons, impacts on the gene pool, and influences of the gene pool, should be considered in all decisions affecting forest lands.

GENE CONSERVATION

One critical issue in forest management decisions is gene conservation, particularly for species that are under harvesting pressures that reduce the level of growing stock. If done improperly, management systems relying solely on natural regeneration can reduce the frequency of desirable genes in a population of trees to a level that cannot be subsequently increased (Mahalovich 1993). In such cases, artificial regeneration can be used to replenish the supply of desirable genes, particularly when it is supported by a tree improvement program.

Tree improvement can assist gene conservation efforts in two ways. First, establishment of genetics plantings (e.g., breeding populations, clone banks, seed orchards, etc.) effectively creates gene repositories that preserve specific genes or genotypes for use as needed. Second, selective breeding among trees in these plantings can help maintain or increase the frequency of specific genes or genotypes.
Past tree improvement efforts contributed to gene conservation, although usually considered as only a secondary benefit. The direct benefits of applied tree improvement to gene conservation should be given more emphasis in the future.

BIODIVERSITY
Another issue important at both the landscape and site level is biodiversity, here referring to both the number of species and variation within species. Although a general discussion of all the issues related to biodiversity is beyond the scope of this plan, several principles related to tree improvement apply. First, using appropriate species is critically important, particularly from a forest health standpoint. At the landscape level it may be possible to intermix several species to increase biodiversity and forest health. At the site level, overstory species selection and silvicultural activities (method of regeneration, spacing, site preparation, release, etc.) impact plant and animal communities and thus biodiversity.

At the site level it is perhaps equally important to consider diversity, or variation as it is more commonly called, within a species. In some cases, such as short rotation intensive culture, highly selected genotypes with little variation may be preferable as a way to maximize fiber growth over a relatively short period. In other cases, such as extended length rotations, more variation within a species on a particular site may be of more value to cope with the wide variety of conditions (weather, pests, etc.) the site would likely experience over the life of the trees.

In these examples and others, tree improvement programs using broadly adapted breeding populations can be an effective tool to address biodiversity issues. Biodiversity and productivity are not mutually exclusive, and in fact may be closely linked (Zobel 1978). Tree improvement programs provide the opportunity to capitalize on such relationships and to develop populations with either wide or narrow genetic variation to suit specific needs.

NON-NATIVE SPECIES
A third issue with implications at both the landscape and site levels is use of non-native species. On the one hand, use of non-native species runs the risk of diluting or reducing the native gene pool, particularly if the non-native species is aggressive and displaces native species. To date there have been no such problems with non-native tree species (e.g., Scots pine, larch, hybrid poplars), but care is required when use of non-native species is considered.

On the other hand, non-native species can provide increased forest productivity and increased genetic variation if used appropriately. Native tree species may have adapted for their ability to survive and reproduce but not necessarily for fast growth or other desirable characteristics. One reason for planting some non-native species is that they may grow faster or have more desirable traits than indigenous species when grown in plantations. Use of these species in high-yield plantations can reduce demands for fiber production on other forest lands and can help offset the loss of timberland due to land use conversion.

Tree breeding programs which use non-native materials can increase overall levels of genetic variation in a species. This is achieved by infusion of new genes that do not exist in native populations or by increasing the frequency of rare alleles. Hybridization is an effective way to incorporate desirable genes from other species into native species. However, non-native species or hybrids should not be used extensively until they are proven by testing in the area in which they will be planted. Instead, use of native genotypes should be emphasized in forest management activities and non-native genotypes should be limited to specific situations where they have been proven.
SILVICULTURAL SYSTEMS
At the site level, silvicultural systems can have a major influence on the genetic makeup of not only tree species, but of all biota on the site. The genetic makeup of the trees on a site, in turn, greatly influences the productivity, health, and biodiversity of the site in the future. For commercial timberland, three specific silvicultural practices for which impacts on genetic makeup of trees on a site should be considered are thinning, harvesting, and reforestation.

Thinning
Removal of some trees in a stand not only increases growing space but also changes to some extent the overall genetic makeup of the remaining trees. The extent of change depends on the species, which trees are removed, and how many are removed. Normally, the genotype will trend toward the phenotype left in the stand. In other words, genes which control certain characteristics are more likely to found in trees which exhibit those characteristics than in those that do not, although the extent to which this is true depends on the specific characteristic in question. For example, Cornelius (1994), looking at studies on nearly twenty different species, found that plus tree selection is generally effective in increasing growth rates of progeny. Conversely, removal of the best trees through high-grading, known as dysgenic selection, often decreases growth rates of progeny (Mahalovich 1993).

Harvesting/Reforestation
Harvesting and reforestation activities are considered in combination since they are frequently interrelated. Harvesting practices can have either more or less impact on genetic makeup at the site level than does thinning, depending on the species mix harvested, type of harvesting system, and method of reforestation.

Clearcut harvesting of an aspen stand that is allowed to regrow will likely result in a stand with approximately the same genetic makeup as the harvested stand, with the exception that more aggressive clones might comprise a larger percentage of the new stand. On the other hand, clearcut harvesting of an aspen stand that is converted to some other species will result in a stand with little genotypic resemblance to its predecessor.

In seed tree or shelterwood systems, the same principles apply as apply to thinning. The genotype of a new stand will resemble the genotype of the trees remaining after harvest. For example, high heritability traits such as tree form can be improved by leaving the best phenotypes. Assuming fewer trees contribute to the gene pool of progeny in a seed tree system than in a shelterwood system, the ability to control the genotype of progeny is slightly higher in a seed tree system. Similarly, genetic variation within the parent trees, and thus the progeny, is likely to be less in a seed tree system than in a shelterwood system.

Artificial reforestation techniques offer the opportunity to establish a stand with the exact genotype desired, if available. Assuming species are chosen which are suitable for the site, stands can be established which contain one or many species, have narrow or broad adaptability, and exhibit one or more specific growth characteristics. Overall, artificial reforestation methods offer the greatest opportunity for controlling the genotype of trees on forested sites. Such artificially reforested forests, or plantations, are rarely "biological deserts." They often provide a variety of outputs during their lives, including soil stabilization, food and cover for various wildlife species, recreation, fiber, and with time, old trees. The specific outputs are highly dependent on the set of management practices imposed on the forest following planting, but again are influenced by genetic makeup of the planted trees.

Finally, the opportunity to combine thinning, harvesting, and reforestation systems to achieve desired outcomes must be recognized. For sprouting species for example, low quality (undesirable) trees can be
reduced in number and their suckers suppressed by residual high quality stems. Given enough time for suckers of the undesirable trees to die out, a naturally regenerated stand following clearcutting would consist of trees almost entirely from the desirable clones.

Other examples of using silvicultural systems to alter the genetic makeup of existing or new stands exist. In short, such systems can be used to shift the genetic makeup of trees and other vegetation on a given site, within limits, in nearly any direction desirable. When consciously considered, the intent has traditionally been to increase productivity on sites by retaining or establishing trees with genetically improved growth rates. However, it has been clearly demonstrated by the practice of high-grading that forest productivity can also be drastically lowered. Thus, if the desire on particular sites is to have crooked trees, or slow growing trees, or trees with nearly any other characteristic, such outcomes are generally possible. The main point is that all forest management activities have genetic consequences that should be considered prior to their application.

**Goal 2. Genetically improved material should be used to increase productivity of Minnesota’s forests.**

One mitigation strategy recommended by the Generic Environmental Impact Statement Study on Timber Harvesting and Forest Management in Minnesota (GEIS) for all harvest levels studied is increasing the wood fiber productivity of timberlands (Jaakko Pöyry Consulting, Inc. 1994:5-128) in Minnesota. This strategy flows from the likelihood that the area of timberland available for harvesting will decrease in the future due to changes in land use, additional reservation of land precluding timber harvesting, and constraints on the types of practices that are permitted on remaining lands.

The mitigation strategy has two elements, each of which can be partially addressed by tree improvement efforts. The first element is increasing utilization, aimed primarily at more complete use of all stems on harvested sites for their best end use. The portions of tree improvement programs that address tree qualities such as stem form, crown shape and size, and fiber characteristics all contribute to individual stems which provide more usable wood than their unimproved counterparts.

The second element in the mitigation strategy is to increase productivity, or fiber production, in existing and future stands. Techniques available to increase productivity in existing stands, and stands created through natural regeneration, were described earlier (see Goal 1). Through proper matching of species with site, full stocking, use of genetically improved material, and intensive management, fiber yield can be dramatically increased over natural stands. Focusing productivity on some lands in this manner can then allow other forest lands to be less intensively managed, or managed for other primary outputs.

Genetically improved material can be used in planted stands to increase both productivity and utilization. Such material is typically developed by applied tree improvement programs through a recurring cycle of selection, breeding, and testing. Some basic tenets of applied tree improvement follow.

**ECONOMIC CONSIDERATIONS**

Zobel and Talbert (1984:6) describe applied tree improvement programs as a "combination of all silvicultural and tree breeding skills . . . to grow the most valuable forest products as quickly as possible and as inexpensively as possible." Traits that are typically the targets of tree improvement efforts include growth rate, crown shape and size, straightness, wood quality, and insect and disease resistance. Genetic improvement of these traits is usually "packaged" as seeds, although other "packages" (e.g., rooted or unrooted cuttings, micro-propagated plantlets, etc.) are also used at times.
An applied tree improvement program typically includes activities such as plus tree selection, establishment of seed orchards, progeny testing, selective breeding, and production of superior clones. For many species in Minnesota, these activities follow decades of provenance test research and are supplemented by current, more basic research in areas such as gene mapping, isozymes, flower initiation, pollen shed and dispersal, and others.

Although there are costs associated with applied tree improvement programs, when done properly they present the opportunity to generate substantial benefits. A review of the literature reveals that, despite different assumptions and methodologies, economic analyses of tree improvement consistently yield strong, positive rates of return. In a study of the Minnesota DNR program, Ford et al. (1983) reported a range of benefit-cost ratios from 0.4 to 17.6 at a 4.4 percent discount rate for first and second generation seed orchards (Table 1). Across the north central region, Stier (1988) calculated benefit-cost ratios of 0.3 to 3.1 at a four percent discount rate for seven species important in Minnesota (Table 2). Risbrudt and McDonald (1986) found a combined benefit-cost ratio of 8.8 at a 4 percent discount rate for programs in the North Central region.

Table 1. Benefit-cost ratios from cash flow analysis at a 4.4 percent discount rate for Minnesota DNR programs (from Ford et al. 1983).

<table>
<thead>
<tr>
<th>Program Component</th>
<th>Red</th>
<th>Jack</th>
<th>White</th>
<th>White</th>
<th>Black</th>
<th>Black</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st gen. grafted seed orchard</td>
<td></td>
<td></td>
<td>14.0</td>
<td>8.7-10.8</td>
<td></td>
<td>17.65</td>
</tr>
<tr>
<td>1st gen. seedling seed orchard</td>
<td>4.2-4.5</td>
<td>6.5</td>
<td></td>
<td>.41-1.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2nd gen. open pollinated SO</td>
<td>13.8-16.2</td>
<td>12.9</td>
<td>16.4-16.8</td>
<td>1.6-5.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2nd gen. control pollinated SO</td>
<td>14.9-15.5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(ranges result from variations in size of the program analyzed)

Table 2. Benefit-cost ratios at a 4 percent discount rate for north central region tree improvement programs (From Stier 1988).

<table>
<thead>
<tr>
<th>Species</th>
<th>Benefit-cost Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Black walnut</td>
<td>3.1</td>
</tr>
<tr>
<td>Aspen</td>
<td>1.3</td>
</tr>
<tr>
<td>Jack pine</td>
<td>2.0</td>
</tr>
<tr>
<td>Red pine</td>
<td>3.1</td>
</tr>
<tr>
<td>White pine</td>
<td>2.6</td>
</tr>
<tr>
<td>Black spruce</td>
<td>0.3</td>
</tr>
<tr>
<td>White spruce</td>
<td>2.4</td>
</tr>
</tbody>
</table>

Applied tree improvement programs have been in existence in Minnesota since the mid-1970s. Genetically improved seed is available for several species and is already being used in reforestation efforts. Use of genetically improved material should continue and expand to help offset the anticipated loss of timberland available for fiber production in the future. It should also be used to help offset losses due to diseases and insects. Such material can help increase utilization by improving the quality of the fiber, and can also help increase productivity by increasing the quantity of fiber grown.
SEED SOURCE CONTROL
In a survey conducted by the Minnesota Tree Improvement Cooperative, land managing organizations in Minnesota indicated an interest in planting of over twenty different species on forest lands they administer. While it would be nearly impossible, and economically unwise, to conduct a high level tree improvement program for every species, it should be possible to implement seed source control over most trees that are planted. Unless proven otherwise, local sources generally survive and grow better than non-local sources and should be used in the absence of other improved material.

To that end, all producers and users of forest reproductive material (seed, seedlings, cuttings, etc.) should document the origin of the material they are using. Without such documentation it is difficult or impossible to ensure that proper sources are used in reforestation activities. Documentation of the origin of reforestation material produced and used within organizations should be systematically recorded, but it does not need to conform to the formal standards set by official certifying agencies. However, documentation for material produced by one organization and used by another should conform to the formal standards. Such conformance provides a level of assurance that the material is what the producer claims it is, which is not otherwise possible.

The Minnesota Crop Improvement Association certifies forest reproductive material using a set of standards developed specifically for Minnesota. The certification program is available to all interested parties. Use of the certification procedures is strongly encouraged for all organizations buying or selling forest reproductive material.

HIGH-LEVEL IMPROVEMENT PROGRAMS
In general, initiation of a high-level improvement program (selection, testing, breeding, seed orchards, etc.) for a particular species should be based on a positive economic analysis, although at times other considerations may come into play. However, caution must be used when conducting and interpreting economic analyses, since what might be economically viable for one organization may not be viable for another. Differences in assumptions, inputs, outputs, and models can all lead to these differences.

Various analyses conducted by several different organizations have shown that high level programs are currently justified for eight species planted in Minnesota. They are aspen, black spruce, white spruce, jack pine, red pine, white pine, red oak, and black walnut. All of the applied genetic improvement programs associated with these species are cooperative in nature, meaning that several organizations are pooling resources to accomplish a common goal. It is doubtful whether a cost effective, high-level improvement program could be conducted for any one of these species by a single organization in Minnesota. Although it remains an option, most organizations do not have the resources to independently support the selection, testing, and breeding work necessary to conduct a high-level program. Details about the improvement programs for these eight species, and larch, are presented under Goal 4.

DEPLOYMENT OF IMPROVED MATERIAL
Several factors must be considered regarding the deployment of genetically improved material, and there is rarely a perfect solution for any given situation. Particularly while it is scarce, genetically improved material should be used on the best sites and provided the most intensive silvicultural treatment that is currently being used. Only under such conditions will the full genetic potential be realized. As the quantity of improved material increases, its use can be extended to a broader range of sites and silvicultural systems following adequate testing.

From an economic point of view, genetically improved material should be used for reforestation purposes as soon after it becomes available as possible. Since there is a cost associated with developing and
producing the material, the more quickly the cost is recovered the more favorable the economics. The only way to recover the cost is to plant the material for its intended purpose. For organizations that are producing and using genetically improved material for internal purposes only, there is no benefit to "banking" improved material or trying to spread it evenly over several years. The maximum amount possible should be used as soon as it is available.

For organizations which produce genetically improved material for external sale, but for which there is not enough material available for it all to be improved, there may be a need to bank improved material and spread its deployment over several years. Such a tactic assures a more even supply of improved material for the external market, and is particularly useful if a premium is charged for improved material relative to unimproved material. As improved material becomes more abundant, the need to spread its production over a longer period will decrease.

Finally, genetically improved material should be used for direct seeding purposes only when there is surplus beyond all other planting needs. Such a surplus does not now exist, nor is an adequate surplus expected for many years. Direct seeding requires many seeds to produce a single, established tree and is an inefficient use of improved seed if there are better alternatives for its use.

Goal 3. Appropriate research should be conducted to support applied tree improvement efforts.

Applied tree improvement programs cannot be separated from research activities that provide both foundational information and answers to very specific questions. Applied improvement efforts today are built on decades of provenance and progeny tests, seed orchard management research, work in pathology and entomology, and other branches of forest biology. In addition, genetic improvement efforts are enhanced because of past research in silviculture, including planting, release, thinning, and harvesting. As in nearly every field, much is known, but much also remains to be learned.

This section does not deal specifically with progeny test research that is part of every applied improvement program. Establishment, management, measurement, and analysis of progeny tests are core elements of such programs and are addressed in Goal 4. Nor does this section consider more fundamental research needs such as gene mapping, isozymes, genetic engineering, etc. Instead, this section identifies high priority, applied research needed to enhance improvement programs.

GENETIC IMPACTS OF THINNING
Empirical measures of the impact thinning has on genotypes and the growth rates of succeeding stands are needed. This is particularly true in cases where natural regeneration is the most prevalent means of reforestation. One specific example is the need to determine the impact on productivity of selectively removing aspen clones prior to final harvest. A second example is studying gene flow and productivity in uneven-aged stands. Such studies, and others like them, are needed so appropriate silvicultural techniques can be used to take advantage of genetic principles in more natural systems.

GENETIC IMPACTS OF NATURAL REGENERATION METHODS
Similar to the situation with thinning, the genetic impact of various natural regeneration systems on succeeding stands needs to be studied. Shelterwood, seed tree, strip cutting, and other natural regeneration systems all have differing impacts on the genetic makeup of the new stands that are created. However, these impacts are not well understood. Research needs to be conducted on the genetic
implications for individual species and stands as a whole. Such information would permit better choices to be made among natural regeneration options.

ESTABLISHMENT TECHNIQUES
Production of genetically improved material (seed or cuttings) is of little value if it cannot be successfully established. Considerable work in the past developed successful establishment techniques for most commercially important conifers in Minnesota. However, much remains to be learned about aspen and red oak, and to a lesser extent black walnut. Elements of regeneration which still need study include stock quality, site preparation, and protection from pests (weeds, insects, diseases, animals).

WHITE PINE BLISTER RUST RESISTANCE
Efforts have been underway for many years to select, and in some cases breed, white pine that is genetically resistant to blister rust. Some resistance has been found, but it has not yet been quantified nor has the mechanism of inheritance of rust resistance been identified. One element in this effort that is sorely needed is a rapid, reliable technique for screening material for resistance at an early age. Until such a system is developed, progress on rust resistance will be slow. More field testing of material with putative rust resistance is also needed.

WHITE PINE SILVICULTURE
Successfully growing white pine, particularly in northeastern Minnesota, requires avoiding deer browse, white pine weevil, and white pine blister rust. At this point, reducing deer browse is perhaps the most critical issue, and work on a reliable, cost-effective technique is continuing. While a solution to the deer browse problem is sought, work must continue on techniques for avoiding blister rust and weevil through silvicultural practices.

SEED ORCHARD MANAGEMENT
"Profitability in a tree improvement program is directly and proportionately influenced by seed yield" (Porterfield 1977). The role of seed orchards is to produce seed, yet there is relatively little information about how to most efficiently do that for the important species in Minnesota. Issues such as soil moisture management, flower induction, pollen enhancement, fertilization, pruning, pollarding, cone and seed insects and diseases, root pruning, influence of micro- and macro-climate, and others all need study for each species. The results would be techniques to efficiently collect larger and more frequent seed crops, thus increasing the economic and genetic benefits of tree improvement programs.

OTHER
The list could be expanded, but enough items were identified above to focus research for the next decade. It is unlikely that all of them will be fully addressed over such a period. Organizations involved in tree improvement efforts in Minnesota should jointly seek funding to address these high priority items.

Goal 4. Applied tree improvement programs should be appropriately sized to match anticipated needs.

As noted earlier, Minnesota organizations are currently participating in high level programs for eight species. As in most parts of the country, tree improvement activities in Minnesota are conducted cooperatively, with several organizations working together toward the common goal of improved material. Such arrangements reduce the cost and effort for individual organizations, compared to working alone, while still making information and improved material readily available to all cooperators.
TREE IMPROVEMENT COOPERATIVES
Most applied tree improvement activities in Minnesota fall under the direction of one of three cooperative programs; The Minnesota Tree Improvement Cooperative (established in 1981), the University of Minnesota/Institute of Paper Science and Technology Aspen/Larch Genetics Cooperative (1989), and the North Central Fine Hardwoods Tree Improvement Cooperative (1986). Each cooperative works on different species, has different (sometimes overlapping) members, covers different geographic areas, and operates with different structures. They were each formed to address specific sets of needs and clients, among which there is relatively little overlap. Each cooperative is described briefly below.

Minnesota Tree Improvement Cooperative
The Minnesota Tree Improvement Cooperative is headquartered at the Cloquet Forestry Center and concentrates on five conifer species; red, jack, and white pine, and black and white spruce. Members are from Minnesota and northern Wisconsin. Past areas of emphasis included seed source control, progeny testing, and first generation seed orchard establishment. Breeding and development of second generation orchards are currently underway.

The Cooperative formed when conifer planting in the state was near its peak and genetic improvement efforts were ready to move from the research phase to the application phase. A substantial amount of work was done by others on silvicultural practices for conifers, so work of the cooperative focused on implementation of genetic principles and practices. The cooperative adopted an approach designed to produce large quantities of seed with a modest amount of genetic gain in as short a time as possible.

Annual dues (or contracts) are paid by members to support a tree improvement specialist (currently half-time) who provides planning, technical, and field assistance to all members. Dues also support a half-time graduate research assistant and minimal clerical support.

University of Minnesota/Institute of Paper Science and Technology Aspen/Larch Genetics Cooperative
The Aspen/Larch cooperative works on aspen and larch with members from across North America. Annual dues, state funding, and grants support a staff of five located at the University's North Central Experiment Station in Grand Rapids. Along with selection and breeding work, the cooperative conducts research on aspen diseases and silviculture.

The Aspen/Larch Cooperative had its roots in the former Institute of Paper Chemistry in Appleton, Wisconsin. When the Institute moved to Georgia, the genetics work on aspen and larch necessarily remained in the north and became affiliated with the University of Minnesota. Because of aspen's wide natural range and the use of Asian (larch) and European (aspen and larch) genetic material, work of the Aspen/Larch cooperative covers a broad geographic area. In addition, the same silvicultural work done on Minnesota's conifers has not been done on aspen or larch, and a substantial portion of the cooperative's efforts are directed along those lines.

Funding for the Aspen/Larch Cooperative comes from a mixture of member dues, Minnesota Agricultural Experiment Station (University of Minnesota) funding, contracts, and grants. Current staffing includes three professional staff, two technical staff, a graduate research assistant, and minimal clerical support.

North Central Fine Hardwoods Tree Improvement Cooperative
The North Central Fine Hardwoods Cooperative is less formally organized, comprising the state forestry organizations in Minnesota, Wisconsin, Illinois, Missouri, Indiana, Iowa, Michigan, and Ohio. They jointly work on tree improvement efforts in red oak and black walnut. Each state supports its own
activities related to the cooperative and there are no dues. Plus tree selection and establishment of clonal seed orchards and breeding arborcta have been the primary activities of the cooperative since it started.

Funding, mostly in-kind, is provided by the state forestry organizations participating in the cooperative. There is no paid staff and the cooperative is not affiliated with a host institution. Administrative duties are shared among state tree improvement specialists and pass from state to state on an annual basis.

**Supporting Cooperatives/Organizations**
Several other organizations provide supporting services to the tree improvement cooperatives. The Forest Vegetation Management Cooperative provides some assistance in seed orchard ground cover management decisions. Expertise and assistance are also provided by individuals from several departments in the University of Minnesota, the Institute of Paper Science and Technology, and the USDA Forest Service (North Central Forest Experiment Station, State and Private Forestry, Region 9).

**HIGH-LEVEL IMPROVEMENT PROGRAMS**
In 1995, 16 different Minnesota organizations were actively participating in the applied tree improvement efforts of one or more of the cooperatives. Table 3 lists the organizations and notes the species for which they have high-level programs. Many of these organizations have interest in several other species besides those marked in the table, but currently are not actively participating in improvement efforts beyond membership in the cooperative. Other organizations that monetarily support these tree improvement activities but do not have active, field-based programs are not listed.

**Table 3. Organizations participating in cooperative tree improvement activities.**

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<td>Blandin Paper Company</td>
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<td>Boise Cascade Corporation</td>
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<td>Champion International Corp.</td>
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<td>Potlatch Corporation</td>
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<td>Rajala Companies</td>
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<td>Itasca County</td>
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<td>Lake County</td>
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<td>St. Louis County</td>
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<tr>
<td>Minnesota DNR-Forestry</td>
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<tr>
<td>Bureau of Indian Affairs</td>
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10
Many organizations located outside Minnesota also participate in the three cooperatives and have substantial influence on cooperative activities. Since this plan is specifically for Minnesota, these other organizations were not listed. However, since species distributions do not follow political boundaries, the role of organizations outside Minnesota is often just as important as the role of organizations inside the state in determining the ultimate direction of tree improvement programs. From an effectiveness standpoint, it would be better to have more improvement programs organized along species distribution boundaries than along political boundaries.

Most organizations have active tree improvement programs for just a few species, reflecting the generally small size of forest land managing organizations in the upper Midwest. The exceptions are the larger organizations (some state DNRs and some private industries) which cover broader geographic areas and manage a wider range of species. As a result, only three organizations listed in Table 3 participate in two or more cooperatives. The rest participate in only one cooperative and usually work on only one or two species.

The present structure and administration of applied tree improvement efforts in Minnesota evolved to meet the needs of the organizations that are participating. Merging the two University of Minnesota-based cooperatives is possible but should be carefully evaluated due to the different focus of each group. At a minimum, communication and cooperation among leaders of the cooperatives should continue and be strengthened in areas such as planning, design, analysis, and other areas that transcend individual species differences.

There are currently eight species for which high-level programs are in place, but the cooperatives and participating organizations are not forever locked into working with only them. For example, white pine and red oak were not on the list ten years ago, but were added in response to increased interest by several organizations. On the other hand, black spruce is decreasing in importance and work on it will be slowed considerably. It is possible for high-level genetic improvement work to begin on a species when enough interest arises and a positive economic outcome is projected. For most forest species, this will mean a substantial artificial regeneration program (about one million trees or more annually) planned over an extended period (25+ years), or perhaps for other justifiable reasons.

It is also possible for individual organizations to initiate genetic improvement programs for species not currently covered by a cooperative. Generally, such programs would be limited to first generation orchards that may or may not be progeny tested. Further work, such as breeding and full-sib progeny testing would probably not be feasible for an individual organization to undertake due to the resources required to accomplish such work.

PLANNING GUIDELINES
The above information provides a background for making plans for applied tree improvement programs in the future. This section deals only with production of improved seed or other material used for regeneration purposes, with the understanding that other genetic principles discussed elsewhere (proper thinning, harvesting, species-site matching, seed source control, etc.) are equally important. Those types of activities should occur on an on-going basis and should be a regular part of all silvicultural decisions. High-level tree improvement activities, on the other hand, require more detailed planning and a long frame of reference.

Because of the long-term nature of tree growth, much of the tree improvement activity being planned now will provide benefits 15 to 30 years from now. Tree improvement efforts should not be viewed as discrete activities, one separate from the other. Rather, they are a continuous series of events, one
building on top of the others. Multiple approaches can be used, generations often overlap, breeding and production populations may be the same or different, and biological time frames may not always match what is expected. Thus, the applied genetic improvement plans presented below for each species do not contain a great deal of detail. They do, however, provide guidelines for improvement activities over the next decade. During that time, activities should be reviewed to make sure they match the needs of participating organizations, and adjusted accordingly.

PROJECTED PLANTING STOCK DEMAND
To help properly size applied tree improvement programs that will be conducted in the next decade, the organizations listed in Table 1 were asked to estimate the number of seedlings of each species they would be planting 20 to 30 years from now. The results are aggregated into four categories: industry, counties, other Minnesota agencies, and non-industrial private forest land owners (NIPF) (Table 4.)

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<tbody>
<tr>
<td>MN Industry</td>
<td>500</td>
<td>1725</td>
<td>100</td>
<td>350</td>
<td>250</td>
<td></td>
<td></td>
<td></td>
<td>300</td>
<td>yes¹</td>
</tr>
<tr>
<td>MN Counties</td>
<td>50</td>
<td>640</td>
<td>555</td>
<td>220</td>
<td>135</td>
<td>365</td>
<td>35</td>
<td></td>
<td>31</td>
<td>yes¹</td>
</tr>
<tr>
<td>MN Gov't</td>
<td>40</td>
<td>1110</td>
<td>1060</td>
<td>576</td>
<td>135</td>
<td>550</td>
<td>100</td>
<td>25</td>
<td>220</td>
<td></td>
</tr>
<tr>
<td>NIPF²</td>
<td>135</td>
<td>2950</td>
<td>200</td>
<td>250</td>
<td>88</td>
<td>1850</td>
<td>175</td>
<td>500</td>
<td>1000+</td>
<td></td>
</tr>
<tr>
<td>MN Total</td>
<td>725</td>
<td>6465</td>
<td>1915</td>
<td>1396</td>
<td>358</td>
<td>3015</td>
<td>135</td>
<td>200</td>
<td>1051</td>
<td>1000+</td>
</tr>
</tbody>
</table>

Other species for which planting programs were estimated are shown below (in 000's):

<table>
<thead>
<tr>
<th>Species</th>
<th>Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Balsam fir</td>
<td>555</td>
</tr>
<tr>
<td>Ash (green, white, black)</td>
<td>500</td>
</tr>
<tr>
<td>Colorado spruce</td>
<td>500</td>
</tr>
<tr>
<td>Black Hills spruce</td>
<td>250</td>
</tr>
<tr>
<td>Scots pine</td>
<td>250</td>
</tr>
<tr>
<td>White cedar</td>
<td>250</td>
</tr>
<tr>
<td>Basswood</td>
<td>200</td>
</tr>
<tr>
<td>Birch (yellow &amp; paper)</td>
<td>200</td>
</tr>
<tr>
<td>Maples (sugar, red, silver)</td>
<td>200</td>
</tr>
<tr>
<td>White oak</td>
<td>100</td>
</tr>
<tr>
<td>Norway spruce</td>
<td>100</td>
</tr>
</tbody>
</table>

¹Several organizations expressed interest in planting hybrid poplar but did not indicate any quantity.
²NIPF: Non-industrial private forest land owner

As shown in Table 4, anticipated planting on non-industrial private forest land accounts for half or more of the total anticipated planting for many species. Clearly these lands will play an increasing role in providing wood fiber and other goods and services in the future. It is important that genetic principles (species selection, silvicultural techniques, gene conservation, genetically improved planting stock, etc.) be applied to these lands as well.

To properly size seed orchards, it was necessary to calculate the number of seeds needed to produce this many seedlings for each species. This was done by estimating the number of seeds needed to produce a plantable seedling (seed efficiency) for each species and multiplying that by the number of seedlings needed. The estimates were derived from information provided by growers (both bareroot and container) in Minnesota and the Woody Plants seed manual (USDA 1974). The seed efficiency values used and the calculated number of seeds needed are shown in Table 5.
Table 5. Seed efficiency and number of seeds needed to provide enough seedlings for anticipated planting programs 20 to 30 years from now.

<table>
<thead>
<tr>
<th></th>
<th>Red pine</th>
<th>Jack pine</th>
<th>White pine</th>
<th>Black spruce</th>
<th>White spruce</th>
<th>Larch</th>
<th>Black walnut</th>
<th>Red oak</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seed efficiency</td>
<td>.80</td>
<td>.50</td>
<td>.46</td>
<td>.45</td>
<td>.27</td>
<td>.47</td>
<td>.32</td>
<td>.60</td>
</tr>
<tr>
<td>Seeds (000's)</td>
<td>906</td>
<td>12930</td>
<td>4202</td>
<td>3084</td>
<td>1326</td>
<td>6443</td>
<td>422</td>
<td>330</td>
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<tr>
<td></td>
<td>2650</td>
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</table>

These numbers are estimates and are readily subject to change. They do not represent absolute values, but can be used to determine the relative size of anticipated planting programs. Despite these shortcomings, the data do provide information that is useful for planning purposes. As noted earlier, if large changes occur in these estimates, adjustments can and will be made in the respective improvement projects to reflect the changes.

SPECIES PLANS
The following sections provide some detail about planned high-level tree improvement activities. Several issues and assumptions related to development of the plans should be noted. First, all the plans were developed using existing programs as a base from which to work. A fairly long history of genetics research and tree improvement activities in Minnesota has, for the most part, provided an adequate set of information and material for use in future programs.

Second, the large number of species that are commercially important in Minnesota's forests dictate that tree improvement resources be spread among them. Thus, too much attention is not given to just one or a few species, since work on other species would undoubtedly suffer.

Third, applied high-level programs are generally designed to meet projected demand for planting stock, and it was assumed that nearly all stock of the species discussed below should be genetically improved. However, high-level programs involve more than just seed orchards, and may include progeny tests, breeding arboreta, clone banks, or other types of plantings. Particularly for seedling seed orchards rogued for seed production purposes, the size of orchards is influenced not only by seed needs, but also by needs for information, gene conservation, and future generations.

Fourth, the size of forest land managing organizations in Minnesota, with the exception of the DNR-Division of Forestry, precludes tree improvement from being the sole duty of any employee. Although many organizations have made substantial investments in tree improvement activities, tree improvement represents only a portion of the work responsibilities assigned to individuals who oversee the activities. Thus, tree improvement programs must be planned and implemented to work in this context.

Finally, the plans presented below evolved from ongoing discussions among members of the organizations, staff of the respective cooperatives, and geneticists across the country. They are not presented with a great deal of detail (e.g., exact breeding schemes, population sizes, etc.) since these elements often change as new information becomes available. However, the plans do provide general guidance about organizational involvement in various species programs and they will continue to be refined as more information is gathered, conditions change, and discussions are held.

Plans are provided for nine species; aspen, jack pine, red pine, white pine, black spruce, white spruce, larch, red oak, and black walnut. There is also a short discussion on hybrid poplars, although no specific
improvement plan is presented. Following the individual species plans, there is a section that discusses the overall tree improvement effort in Minnesota.

**Aspen**

Approximately 50 percent of the timber harvested in Minnesota is aspen. Increasing growth rates through genetic improvement could have significant impacts on wood supply. A projected decline in availability over the next 15 to 20 years has increased the urgency of establishing faster growing clones. Although genetic gains in growth rate have been quite promising, techniques for establishing new clones on a site are not yet completely reliable. If and when these techniques are available, demand for aspen planting stock in Minnesota may increase substantially.

Because aspen is so widely distributed, the improvement program in Minnesota is only part of the total effort and plans necessarily reflect interest and activities across North America. Substantial interest in aspen exists in Canada and there is renewed interest in Michigan and Wisconsin. The demand for aspen and aspen hybrid planting stock by six organizations (three in Minnesota) is expected to increase from about 1.3 million in the short term to about 2 million in the mid term. In Minnesota, the long term demand (20 to 30 years) is low (Table 4), due at least in part to projected availability of stumpage after 2010. However, as noted earlier, demand is expected to increase as plantation establishment success increases and as new materials become available. Additional demand is also expected as clonal materials are developed for biomass planting on marginal farmlands.

The Aspen/Larch Cooperative has developed a long-term breeding strategy for the improvement of aspen and aspen hybrids and is establishing progeny tests to identify the best parent trees. Early selection and accelerated breeding techniques will reduce the length of time between breeding cycles. The genetic base is being broadened by selecting up to 300 aspen trees from Minnesota, Wisconsin, and Michigan and 100 aspen trees from Saskatchewan and Alberta. In addition, *P. tremula* plantings are being established for future selection work. All this material is being cloned by grafting and archived at an arboretum near Grand Rapids. Both traditional seed orchards and potted orchards have been established and seed is currently being produced in each setting.

**Jack Pine**

There are currently nine first generation jack pine seed orchards in Minnesota covering approximately 26 acres. They were established during a 14 year period and include over 600 different families. The large number of plantings and families established over a long period is primarily a function of responding to the needs of individual cooperators and testing the importance of using local seed sources.

Controlled pollinations are currently underway that will lead to development of second generation full-sib progeny tests. These will eventually be rogued and used as seed orchards. Four orchards will be established, each about 4.4 acres in size. One will be located just south of Eveleth (managed jointly by IRRRB and St. Louis County), one near Bemidji (DNR), one near Brainerd (Crow Wing County and others), and one near Cloquet (Pottawattamie). Each orchard will contain an identical set of approximately 150 unrelated full-sib families.

The projected demand for planting stock would require approximately 11 acres of orchard, assuming yield projections are reasonably accurate. The planned orchards will cover about 17.6 acres, primarily because of progeny test design considerations and the need to maintain an appropriate genetic base. The additional 6 acres will also allow earlier production of the necessary number of seeds and provide some buffer against potential loss of seed orchard acres or seed production capabilities.
Red Pine
There are currently five first generation red pine seedling seed orchards in Minnesota covering approximately 25.5 acres. They were planted from 1981 through 1991 and contain all or some of 220 families. If yield projections are accurate, these orchards can produce an average of about 3 million seeds annually beginning in 5 to 10 years and lasting for 15 to 20 years. The anticipated demand in Minnesota 20 to 30 years from now is for about 10.6 million seeds annually.

If all planting stock is to be genetically improved, red pine seed orchard acreage will need to be tripled. It makes little sense at this time to establish additional orchards using the original seed, since it has already been progeny tested and better performing families can be identified. Thus, any new orchards should be established using second generation material.

Although red pine exhibits relatively little genetic variation, economic analyses conducted by several members of the Minnesota Tree Improvement Cooperative showed that tree improvement efforts are cost effective. Because it is the most-planted species in the state, costs associated with tree improvement efforts can be spread over many seedlings (or acres). In addition, successful silvicultural systems (establishment, release, thinning, harvest) have been developed for red pine, increasing the consistency with which planted seedlings can be turned into harvestable wood. Finally, when grown to sawtimber size, red pine produces a valuable product. All these factors lead to positive cost-benefit analyses of tree improvement efforts in red pine, even though genetic variability is lower than in other species.

To take full advantage of the opportunities presented by red pine, fully pedigreed second generation orchards should be established to get as much genetic gain as possible. Although the final numbers need to be determined, approximately 100 to 150 unrelated full-sib families should be created by crossing the best trees in the three orchards established in 1981 (2 DNR orchards, 1 Potlatch orchard). Such crossing should be possible beginning in the late 1990s.

To meet the anticipated seed need for state land planting and nursery sales, the Minnesota DNR needs about 6 million seeds annually. Based on current yield projections, this will require about 40 to 50 acres of seed orchard. Other Minnesota organizations will require about 4.5 million seeds 20 to 30 years from now, requiring about 35 acres of seed orchard, for a total of about 80 acres of red pine seed orchard. However, if intensive orchard management techniques are used (e.g., irrigation, fertilization, flower induction, pollen enhancement, etc.), the size of the orchards can perhaps be reduced. Existing orchards should be used to gain experience in cone collection techniques, flower induction, pollen enhancement, and information about seed yields. Such experience and information will be useful in properly sizing and managing future orchards.

Actual establishment of the orchards will probably occur about ten years from now, so it is too early to decide their exact location or who might establish them. However, several principles should be applied. First, a few large orchards are preferable to many small orchards. Large orchards are more efficient for both administrative and biological reasons, particularly if intensive orchard management techniques are used. Second, the orchards should not be concentrated in a small geographic area. This reduces the risk of catastrophic loss or reduced seed production due to isolated, temporary environmental factors (e.g., weather phenomena, insect outbreaks, etc.).

White Pine
Anticipated demand for planting stock 20 to 30 years from now is about 1.3 million seedlings, requiring about 2 million seeds. If yield estimates are correct, about 24 acres of seed orchard will be required to
produce this much seed. However, because of issues related to blister rust, establishment of seed orchards is not as straightforward for white pine as it is for many other species.

Two approaches to blister rust are being taken. The first approach is selecting and breeding clones for resistance to blister rust. Past efforts have provided some apparent resistance, although it is not yet possible to quantify the amount of resistance. Such efforts are continuing and the Minnesota Tree Improvement Cooperative is actively involved in these efforts.

The second approach is aimed at selecting and breeding clones for rapid growth rate, under the assumption that blister rust can often be avoided by using proper silvicultural techniques aided by fast growing trees. This approach also recognizes that deer browse and white pine weevil significantly impact growth of white pine, and that increasing growth rates may help reduce these impacts as well.

Both efforts should continue and it may be possible to combine them at some point in the future to generate material that exhibits both rust resistance and faster growth rates. Until they are combined, seed that has some rust resistance should be used primarily in the highest rust hazard zones. Seed that has improved growth rate should be used only in areas outside the highest rust hazard zone.

Currently, there are two orchards covering 4.1 acres that contain clones selected for rust resistance. There is one orchard in the process of development (scion collection and grafting) that will cover about five acres and will contain clones selected primarily for growth rate. To fulfill the projected demand for seed, another 10 acres of seed orchard is needed, probably divided about equally between rust resistance and growth rate.

On the rust resistance side, St. Louis County will expand their white pine orchard, adding about 2 acres. The Minnesota DNR should expand their St. Francis orchard by about 3 acres. Efforts will continue to graft clones from the Tofte planting into the breeding arboretum at the Cloquet Forestry Center.

Itasca County and Rajala Companies will continue developing their 5 acre orchard, which is designed primarily to increase growth rates. An additional 5 acre orchard should be established using similar material. IRRRB is perhaps the logical organization to take the lead in establishing this orchard, although another organization may want to do so. Once the orchards are established, it will be necessary to progeny test all the clones contained in them. However, this effort is still too far away to plan in any detail at this time.

For all orchard establishment or expansion, bench grafting (or field grafting at General Andrews Nursery) is recommended. Following bench grafting, the ramets should be transplanted to nursery beds until they are large enough to be moved to the orchard.

**Black Spruce**

Planting programs for black spruce in Minnesota are expected to be quite small in the future. In addition, economic analyses for black spruce genetic improvement programs generally show small benefits relative to costs. For these reasons, the Minnesota Tree Improvement Cooperative decided to not proceed with advanced generation tree improvement efforts in the foreseeable future. The five existing first generation and generation-and-a-half seed orchards should adequately fill the demand for seed over the next decade. Trees in the orchards should be managed to keep them short enough to allow cone collection without resorting to hydraulic lift equipment. Some research effort is needed to determine the impacts of pruning and pollarding on cone production in black spruce. If in the future it is determined that black spruce tree
improvement efforts should accelerate, the base of material and information that already exists will be readily available.

**White spruce**
The projected demand for white spruce planting stock in 20 to 30 years is about 3 million seedlings annually, much of which is apparently headed for non-industrial private forest lands. Approximately 6 million seeds will be needed to meet this demand. Existing seed orchards cover approximately 20 acres and at full production will be able to produce about 13 million seedlings annually. These orchards were established to meet a demand projected 20 years ago that did not completely materialize and is projected to go down.

White spruce is one of the most genetically variable timber species in Minnesota, and thus substantial improvements in growth rate are possible. Information from a white spruce progeny test will be used to rogue existing seed orchards, graft outstanding individuals for 1.5 generation seed orchards, and make controlled pollinations among selected clones to establish a full-sib progeny test. Measurement of the progeny test is scheduled for the fall of 1995, and it should be possible to begin these efforts shortly after that.

About 10 acres of second generation white spruce seed orchard are needed to supply the projected demand for planting stock. Depending on arrangements made among cooperators, this should all be located in only one or two orchards.

**Larch**
Only minor amounts of larch are expected to be planted in Minnesota 20 to 30 years from now and most of the genetic improvement work on larch is done by organizations outside the state. However, interest in larch is very high among these organizations, which plant approximately 2500 acres annually. About 50 kilograms of seed are acquired each year from sources outside members of the Aspen/Larch Cooperative, and the amount will probably increase until seed orchards and seed production areas are in production. Interest in Minnesota is just beginning, and seed demands may increase as members become aware of larch's utility in their planting programs.

Larch selections were established in an arboretum near Grand Rapids and new selections are being made. Controlled pollinations among the selections are now underway and flower stimulation techniques to accelerate breeding are being investigated. Wood quality was investigated and pulping properties are very good. In addition, the potential for solid wood products is being investigated in cooperation with the University of New Brunswick. The addition of tamarack and possibly Siberian larch to the program is being considered, since both species may offer frost resistance and are capable of rapid growth.

**Black Walnut**
The Minnesota DNR has been working on black walnut tree improvement since the early 1980s. At that time, activities such as plus tree selection and grafting were coordinated by the Minnesota Tree Improvement Cooperative. During this period, approximately 60 plus trees were selected. In 1986, the Fine Hardwoods Cooperative formed with the DNR as a charter member. This cooperative assumed responsibility for the development of breeding strategies, progeny tests, and seed orchards. Procurement of Federal Focused Funds greatly accelerated the pace of selection, grafting, and seed orchard development.

The Fine Hardwoods Cooperative developed a 10-year plan that included delineation of breeding zones, determination of breeding strategies, and program goals. Southeastern Minnesota, the extent of black
walnut's range in the state, was included in Breeding Zone 1 with Wisconsin, northeastern Iowa, and northern Illinois. Within each zone, the population of selected plus trees is subdivided into small breeding sublines of 25 to 30 clones each. Minimum goals of 300 plus trees and 10 sublines were set for each breeding zone. These goals were met in Breeding Zone 1 in 1991. The Minnesota DNR selected and propagated, by grafting, nearly 150 plus trees, and manages five breeding sublines.

The Minnesota DNR manages two walnut seed orchards, comprising 9 acres. Neither of these orchards has produced seed yet. Information regarding potential walnut orchard seed production is lacking, making estimates of future nut production difficult. In the two orchards combined there will be about 600 trees, leading to a potential annual production of 90,000 nuts. This seed production will adequately meet the state land seeding demand of 25,000 (requiring about 40,000 nuts), but will fall short of satisfying the expected demand from non-industrial private forest landowners.

At this time there are no plans to increase the number or size of the black walnut seed orchards. When more information about nut production and performance of the material produced in the orchard is available, additional orchards may be established.

**Northern Red Oak**

Northern red oak was also selected by the Fine Hardwood Cooperative for high level tree improvement efforts in 1986. Breeding zones were delineated and a sublining breeding strategy adopted. Minimum program goals of 300 plus trees and 10 sublines per breeding zone were set. Because the member states had differing program priorities, most decided to complete development of first generation walnut populations before working on red oak. Others moved quickly to high level tree improvement activities. The Minnesota DNR began red oak selection and grafting work in 1990.

The commercial range of northern red oak in Minnesota runs from Grand Rapids and Duluth in the north to the Iowa border in the south. This required the development of two breeding zones, one for central Minnesota and one for the southeastern part of the state. In each zone, more than 50 plus trees have been selected and grafted. Two sublines of 25 clones each were established for each zone. A seed orchard was planted in each zone, near Moose Lake for central Minnesota and at Faribault for the southeastern part of the state.

The small, first generation orchards established by the Minnesota DNR will produce only a small fraction of the forecast seedling demand. Limited program resources prohibit the establishment of larger orchards at this time. When seed is produced in the orchards it will be used for state land reforestation. Second generation orchards containing progeny tested selections of much higher genetic worth will likely be larger, increasing the percentage of forest land regenerated with improved seedlings. However, initiation of these second generation orchards is still more than ten years away.

**Hybrid Poplar**

Six Minnesota organizations showed an interest in planting hybrid poplar in the future, although most were unsure of quantities. Establishment, growth, and yield research is currently conducted by individuals in the Natural Resources Research Institute and the University of Minnesota - Crookston, with participation in some work by energy companies. Genetics work has been limited to species trials, and to date little hybrid poplar breeding work has occurred in Minnesota. Efforts are underway to increase funding for hybrid poplar research, some of which may relate to development of new hybrids or clones. If additional funding is available, such work could reside in either the Minnesota Tree Improvement Cooperative or the Aspen/Larch Cooperative.
Other species
Many other species than the ten listed above grow in Minnesota's forests and could be considered for high-level genetic improvement activities. Limited resources and economic prudence dictate that improvement efforts be undertaken for only the highest priority species. Depending on a sustained interest level and additional resources, high-level improvement programs could be considered for balsam fir and perhaps the ash species. It is doubtful if any other species will warrant such activity.

TREE IMPROVEMENT IN MINNESOTA
While it is necessary to make plans for the genetic improvement of individual species, tree improvement programs in Minnesota are, and will continue to be, successful because of their cooperative nature. This is true not only in applied programs, but also in research efforts where several units of the University of Minnesota and the USDA Forest Service provide a large research capability. All organizations benefit from the work done by other organizations, and information is widely available to everyone.

As applied tree improvement activities in Minnesota progress there are two issues that need to be addressed. The first deals with multi-organizational management of seed orchards, the second deals with potential collaboration in applied tree improvement efforts with the national forests in Minnesota. Each is discussed below.

Multi-organization management of seed orchards
From an efficiency standpoint, it is preferable to have a few large seed orchards rather than many small orchards covering the same area. The impact of foreign pollen is reduced in large orchards and management operations which have relatively large fixed costs (e.g., irrigation systems, weather data collection systems, maintenance equipment, etc.) can be more efficiently used. Additionally, travel time is reduced, overhead costs per unit are reduced, and other efficiencies can be realized. In the same way, several orchards of different species located at one site provide even more efficiencies and such arrangements are encouraged whenever possible.

Because of the size of planting programs for most Minnesota organizations, orchards that serve the seed needs of only one organization are often quite small, normally ranging from 1 to 5 acres. There are very good reasons for establishing small orchards that serve the seed needs of only one organization. However, the general direction tree improvement should head in Minnesota is toward fewer and larger orchards. In a few cases, organizations may have large programs that let them manage an orchard of a particular species for their needs only. More frequently, several organizations will need to reach agreements that allow equitable distribution of both costs and benefits (normally seeds) related to establishment and management of a seed orchard that fulfills all their needs.

Several methods exist to make such arrangements, and the following issues should be addressed. First, who will own the orchard (i.e., on whose property will it be located)? Second, how will costs of establishment, management, and seed/cone collection be shared (e.g., recovered when seed is sold, cash payments, in-kind payments)? Third, how will seed be distributed among partner organizations (e.g., sold at cost, sold at profit, split via formula, traded for other seed, etc.)? Finally, what formal agreement, if any, is needed among organizations participating in such arrangements?

From experience and ongoing discussions, it appears that these issues can be resolved among the various organizations. If they can, fewer and larger orchards will likely be established in the future. If they cannot be resolved, orchards will likely remain smaller and will be sized to fit the specific needs of one or just a few organizations.
Collaboration with national forests
The National Forest System has traditionally conducted its own applied tree improvement program, separate from efforts at the state level. Their approach has been to cooperate, but not belong to or participate in the activities of cooperatives. Cooperation has generally been good, but the result has been parallel programs working toward the same goals with relatively little interaction. White pine, white spruce, and red oak are species where substantial benefit could be gained by all parties if closer working relationships were developed between the cooperatives, the national forests in Minnesota, and the Forest Service tree improvement program. Additional benefit may also occur in jack pine, red pine, and aspen.

Forestry organizations across Minnesota, including the national forests, are being asked to do landscape level planning so that the needs of all landowners, the public, and the ecosystem are better served. Although there are historical and mandated reasons why the Forest Service has not participated more fully in the cooperatives, the opportunity may now exist to develop better collaboration. Guidance and encouragement by major forest land owners in the state are needed to accomplish this objective.

Goal 5. Tree improvement efforts in Minnesota should be focused, coordinated, and adequately funded.

There are limited funds to conduct applied tree improvement programs in Minnesota, and they must be used as efficiently as possible. This is best accomplished by working on appropriate species and coordinating efforts to avoid duplication. However, focused and coordinated efforts have meaning only in the context of adequate funding, as discussed below.

SPECIES PRIORITIES
One method used to allocate scarce tree improvement funding is to prioritize species based on their biological potential for improvement, size of the planting program, their economic return, their ecological importance, or other criteria. However, prioritizing species in terms of the value of conducting applied tree improvement programs is largely a matter of perspective. Some species are of extreme value to some organizations and of almost no value to other organizations.

Through cooperative improvement programs that continuously evaluate where efforts should be devoted, a consensus has arisen that for the next decade, seven species are of equally high priority for improvement efforts in Minnesota. They are aspen, jack pine, red pine, white pine, white spruce, red oak, and black walnut. Because larch is a high priority species outside Minnesota and offers potential value in the state, the Aspen/Larch cooperative will continue high-level tree improvement activities. The level of tree improvement activity that should be devoted to hybrid poplar is unknown at this time. With work on eight species already stretching limited resources, there is reluctance to add another species to program efforts until there is a clearly defined, long-term commitment to the species. Much of the commitment depends on conservation programs and the economic viability of short rotation intensive culture for biomass production in predominantly agricultural areas.

Thus, high-level programs, of approximately equal intensity, should be maintained for all eight species listed above. Individual organizations have the opportunity to select which species they want to become involved with and at what level. That choice must remain with each organization. However, the cooperative nature of the programs also allows organizations to get information and material for species in which they do not have active genetic improvement programs.
COORDINATION

Some concern has been expressed that applied tree improvement programs in Minnesota are not coordinated among organizations, that more seed orchards exist than are needed, and that too many dollars are being spent on such programs. In reality, the available information argues for the opposite viewpoint. Cooperative staff members spend a substantial amount of time planning programs, working with organizations in the field, sharing results and information, and communicating with members to make sure that efforts are coordinated. In addition, the Minnesota Tree Improvement Cooperative will renew its listing of available improved seed (either still on the tree or in storage) so that improved seed will be used to the greatest extent possible.

Only for white spruce are there possibly more seed orchards than needed. However, this is true only if all orchards reach full production simultaneously. At present, there is still not enough improved seed to meet all the demand and when white spruce orchards are rogued there will be a drop in seed production for several years. Thus, a persistent excess of white spruce seed is not expected in the near future, if it occurs at all. In all other cases, seed orchards are either appropriately sized for demand or are undersized. For red pine and red oak, there are severe shortages of seed orchards.

FUNDING

Funding of research in general and tree improvement efforts specifically is problematic. Setting aside for the moment the basic research that complements it, applied tree improvement programs still contain a combination of lab research, test plantings, production plantings, field trials, field research, statistical analysis, and professional judgement. In addition, they are often closely linked to silvicultural techniques, creating new sets of relationships that need to be tested, measured, and analyzed. Improvement efforts involve both research and application, but do not fit neatly into either category. Although this might have some advantages when it comes to funding, a more common pattern is that the parts of organizations that do research view tree improvement as applied work, those involved with application often view it as research, and neither side provides adequate funding.

Ellefson (1994:44-45) describes the types of conditions where private or public funding of research activities is likely to occur. Applied tree improvement activities in Minnesota, including both the research and production components, satisfy some conditions for each type of funding. Conditions which encourage private sector funding and exist with respect to tree improvement efforts in Minnesota include little uncertainty regarding the pay-off from investments, economically scarce forest resources, and modest costs to establish and manage research programs. Conditions that normally lead to public sector funding include many small private forest holdings, a large amount of publicly-owned forest, fragmented and small unit wood-based industries, forest benefits existing as public goods, and social goals to enhance rural forestry development.

Current funding

Both the private and public sectors fund applied tree improvement activities (the cooperatives) in Minnesota. Besides the costs associated with establishing and managing genetics plantings, the private sector in Minnesota supplies about $36,000 annually to support activities of the cooperatives ($20,000 to the Minnesota Tree Improvement Cooperative, $16,000 to the Aspen/Larch Cooperative).

Public sector funding (not including counties) is about $180,000 annually. The Aspen/Larch Cooperative currently receives about $150,000 of state funds annually through the Minnesota Agricultural Experiment Station (MAES), administered by the University's Department of Forest Resources, and $4,000 from the DNR-Division of Forestry. A significant portion of the MAES funding is spent on clonal propagation techniques, stock quality improvement, and establishment techniques. The Minnesota Tree Improvement
Cooperative receives about $5,000 of MAES funding and about $22,000 from the DNR, Bureau of Indian Affairs, and the Iron Range Resources and Rehabilitation Board combined. The Fine Hardwoods Cooperative receives only in-kind support through the DNR, but no other public sector funding.

State funding and other grants support research activities of two approximately 50 percent time faculty and associates in the area of forest genetics with the University's Department of Forest Resources. These faculty conduct basic and applied forest genetics research in Minnesota and serve as advisors to the cooperatives.

Counties were not included with other public sector funding since most county land departments act more like profit centers, where receipts from forest management activities must cover costs. Thus, their participation in tree improvement activities is more similar to private sector participation than it is to public sector participation, in the fact that cost-benefit analyses play a major role in the level of activity. Minnesota counties provide about $10,000 annually to the Minnesota Tree Improvement Cooperative and about $12,000 annually to the Aspen/Larch Cooperative. Counties provide no funding to the Fine Hardwoods Cooperative.

The cooperatives use the funding described above to provide technical, field, and research assistance to organizations, and to coordinate efforts among them. If the work that is not directly related to tree improvement (e.g., propagation techniques, establishment techniques, etc.) is removed, the cost of research, assistance, and coordination activities by the cooperatives is about $150,000 annually. Organizations participating in the cooperatives collectively spend another $150,000 to $200,000 annually to actually conduct the programs. The technical and coordinating roles played by the cooperatives allow this money to be spent as efficiently as possible.

**Funding needs**

One mitigation strategy identified in the GEIS was to increase productivity of timberlands. Although not the only component of this strategy, tree improvement efforts aimed at improving wood quality, form, disease resistance, and growth rate must be considered a key component. If such efforts are going to be effective, more funding will be necessary in the future, particularly with the conifer species and high value hardwoods. Addition funding would permit completion of critical work in a timely fashion for the benefit of all forestry interests in the state.

Funding for the Aspen/Larch Cooperative is considered adequate at this time. The large annual MAES appropriation provides base funding and staff which is leveraged to produce additional grants and contracts.

The Minnesota Tree Improvement Cooperative serves a broad group of Minnesota organizations and tree improvement needs and its funding should be put on equal footing with the Aspen/Larch Cooperative. At a minimum, state funding for the Minnesota Tree Improvement Cooperative should be increased to support two full-time equivalents (approximately $60,000 additional funding annually). The additional staff would be used to address some of the research issues listed under Goal 3. They would also be used to complete projects more quickly (e.g., breeding work), and to seek other sources of funding.

Direct funding for the Fine Hardwoods Cooperative should be initiated to support one full-time equivalent (approximately $60,000 funding annually). Such funding could be applied directly to the DNR-Division of Forestry to assist with their oak and walnut improvement efforts. Alternatively, a portion of the funding could be directed to the University of Minnesota to provide an institutional home for the Fine Hardwoods Cooperative and to broaden its scope to other interested organizations.
Summary

Applied tree improvement programs in Minnesota have only about a 15 year history, yet much has already been accomplished. Improved seed has been collected from seed orchards of six species and work is beginning on second generation orchards for several species. Genetically improved seedlings are being planted for a variety of uses and organizations are already beginning to recover some of the costs associated with their tree improvement programs.

New challenges face forest land managers in Minnesota that will require provision of more goods and services from the forest resource, while maintaining and perhaps increasing the wood supply. Increases in productivity are required, but issues such as gene conservation, biodiversity, extended rotations, and others need to be considered.

Tree improvement efforts can play a significant role in addressing these issues. To do so, both coordinating efforts (the cooperatives) and implementation efforts (genetics plantings, research activities, breeding, testing, etc.) are required. The cooperatives are providing guidance to organizations for genetic improvement of nine species and several major research efforts are needed to support these applied programs.

Current funding for coordinating efforts, particularly for conifers and the fine hardwoods, is inadequate to meet the research and application needs. A lack of sufficient funding in tree improvement programs may hamper gene conservation efforts and will mean a shortage of improved seed, slower rates of improvement as breeding programs are delayed due to lack of resources, and ultimately, lower productivity of Minnesota's forests than is possible. This will occur at the very time when gene conservation, increased biodiversity, broadly adapted genotypes, and timber productivity are all increasingly important.

Literature cited


