Wisconsin Department of Natural Resources
Forest Genetics Program

Strategic Plan
2009-2019

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Introduction

Justification for a Forest Genetics Program in Wisconsin

Any forest management system which uses artificial regeneration as a tool relies on genetic materials to propagate by seed or cutting the various species being regenerated. If these genetic materials are of poor quality, the resulting forest will be of poor quality, or at least less productive than it could have been. If these genetic materials are of superior quality, then the resulting forest can be more productive and more valuable than the forest that preceded it. The assurance of quality genetic materials for the forests of Wisconsin comes from the Department of Natural Resources' (DNR) Forest Genetics program which ensures that the seed used for growing forest nursery stock is biologically sound. It also ensures that the seed supply comes from a broad base that conserves the genetic resources of the State's forest tree species.

Historic Relevance

The DNR has been involved in a Forest Genetics program since 1948 with longstanding partnerships with the University of Wisconsin-Madison and USDA-Forest Service. In 1983, a Strategic Plan for Wisconsin's Forests (Lindberg and Hoven, 1983) recommended pursuit of an aggressive management program for the state forest nurseries, including the need for a tree improvement program to provide genetically improved seed for the state nursery program.

Sustainable Forestry

The 2004 Statewide Forest Plan (Division of Forestry 2004) identified multiple objectives on the theme of sustainable forestry which provides additional justification for a Forest Genetics program. Objective 30 of the plan is to "Maintain an adequate supply of quality nursery seedlings for Wisconsin's conservation needs." The quality of these seedlings is dependent on the management of the program that produces them. Objective 3, 5 and 7 call for the conservation of native tree species and biodiversity, which relates directly to the gene conservation aspects of the forest genetics program. Finally, Objective 20 is to "Encourage forest management practices and the production of forest products that sustainably meet the needs of current generations while providing adequate resources to meet the needs of the future". Here again, a forest genetics program is relevant in providing seed that yields a more productive forest, with trees having better form and growth and better tolerance of pests than those of the previous rotation.

Changing Climate

A Forest Genetics program may become even more relevant in the future as the impacts of climate change become apparent across the landscape. The 2004 Statewide Forest Plan's issue 15 notes that "warming of the earth may affect forest composition, structure and function." The extent to which this will occur is highly dependent on the genetic adaptability of forest species. A Forest Genetics program will be critical to assessing the extent to which species may adapt or migrate under various climate change scenarios; genetic adaption is a strong force in determining how "climate envelope models" will transfer to the landscape (Mckinney et al. 2007).

Purpose of a Forest Genetics Program Plan

All research and development programs – including Wisconsin's forest genetics program - require periodic assessment to review and update program directions and provide for program planning. This current plan spells out the goals, priorities, and responsibilities of the various individuals and organizations involved in

Wisconsin's forest genetics program through the year 2019. The plan also recommends a schedule of activities for achieving short-and long-term objectives, yet provides for needed flexibility should economic or biological constraints require a change in strategy or program direction. Program planning serves to:

1. define program goals and objectives. Goals and objectives serve as a focal point for organization and discussion of resource use and frequently help to direct the establishment of program priorities. If the program is to continue to succeed, there must be a consensus among participants as to the direction of current and future efforts as embodied in the programs goals and objectives.

2. establish program priorities. Priority-setting is required as financial and personnel support levels are finite. Some activities necessarily suffer at the expense of others, but a judicious setting of priorities will maximize return on investments while maintaining a broad base of activities should future demands dictate program shifts.

3. ensure program continuity. Tree improvement activities are expensive, long-term propositions which usually outlive their originators. Effective program planning minimizes the loss of information and lapses in maintenance that often follow personnel changes. One purpose of the tree improvement program plan is to secure the long-term continuity required for successful tree improvement activities.

4. allocate responsibilities and schedule activities. It must be clearly understood that each party assumes certain responsibilities in program development and conduct, and that a failure to satisfy such responsibilities jeopardizes the entire program. Tree improvement programs are constructed in such fashion that sequential steps must be completed at specified times if long-term efforts are to be successful.

5. facilitate financial planning. Carefully scheduled tree improvement activities permit timely budget requests and allocations to be made to provide necessary program support, both financial and personnel, and continuity at critical junctures in the program.

Goals and Scope of the Wisconsin Forest Genetics Program

Program Goals

In this plan, goals are viewed as ideals that cannot be precisely quantified in terms of time or cost requirements to completion. Goals may or may not be attainable during the life of the plan. They serve as targets for overall program direction. Within this framework, the tree improvement program in Wisconsin has two important goals:

1. the development of biologically sound tree improvement practices that lead to increases in forest productivity and forest health on forest lands in Wisconsin;

2. the conservation of forest genetic resources in long-term breeding programs in order to maintain a broad genetic base that can provide future ecological benefits and accommodate potential future changes in climate, pest pressures, forest management practices, or demand for products.

The first goal relates to the process of tree breeding and domestication, which can be approached in a manner familiar to all plant breeders. Within the limits of genetic potential, we wish to select and propagate trees that provide products valuable to human use. The second goal relates to questions of ethics and gene conservation that must be addressed at regional and national levels. Our concern is to minimize the erosion of genetic variation in native populations and in long-term domestication programs. This second goal is directly related to the Department's mission of preserving biodiversity, especially at the genetic level (Addis et al., 1995) as well as the 2004 Statewide Forest Plan objective to “Conserve, protect, and manage for biological diversity and support continuing research on biological and ecosystem diversity.” Both goals are integral parts of a long-term tree improvement program.

In the short-term our efforts concentrate on using available information and resources to continue to improve the genetic quality of our present-day forest tree nursery stock. Significant achievements are possible here while also advancing investigations into conservation and breeding activities for species with great ecosystem restoration value.

Our long-term efforts involve maintaining a broad genetic base so that future selection and breeding efforts are not constrained by an impoverished genetic resource, e.g. maintaining biodiversity at the genetic level. This broad genetic base will be especially important for species under threat from climate change as well as other climate stressors.

Scope of the Plan

Duration of Present Plan

Tree breeding activities are necessarily long-term, in part because of the longevity of trees and the long age to sexual maturity for many tree species, but also because of the open-ended opportunities for obtaining genetic gains in successive generations through breeding efforts. However, for planning purposes some finite time frame is required. This plan outlines directions for tree improvement activities in Wisconsin through the year 2019, a span of ten years from the present. Considerable latitude will be required for annual work planning, both in scheduling short-term activities due to biological constraints, and in accommodating small shifts in program emphasis.

Improvement and Conservation Levels

Tree improvement activities may proceed at varying levels of intensity depending upon time, space, cost constraints, and the level of improvement considered acceptable. Proceeding from least intensive to most intensive, forest geneticists recognize seed zoning, seed collection areas, seed production areas, and seed orchards as four major approaches to producing improved seed. Certain approaches, such as seed orchards, can be subdivided on the basis of clonal versus seedling propagules, but the basic hierarchy remains unchanged.

Different levels of intensity, and different approaches to tree improvement, are necessary for different species. No one method appears universally suited for all species due to different program priorities, budgetary constraints, the unique biology of different species, and availability of genetic information. Since the writing of the last 1998-2007 strategic plan, new genetic technologies have become more popular – especially with economically important agronomic crops - but also have kindled ethical debates concerning the use of Genetically Modified Organisms (GMOs). These technologies include somatic embryogenesis and direct gene insertion using various vectors. Currently, the Wisconsin DNR uses only native species in its reforestation operations. In addition, our forest genetics program lacks the resources to pursue the complex and expensive approaches favored by some agricultural enterprises. The production of GMOs will not be considered in this plan.

Resources

Personnel

Wisconsin Department of Natural Resources state nursery and forestry program personnel have played important roles in the establishment and management of forest genetics plantings throughout Wisconsin. This cooperation is expected to continue, and even increase, in the future. At the present time, permanent and seasonal staff provides manpower for maintenance activities in the program. In the future it is expected that the assistant manager at each nursery will undertake monitoring and maintenance of forest genetics plantings within their regions. The Division of Forestry employs a forest geneticist/nursery specialist whose major responsibility is the planning and coordination of tree improvement and state nursery activities in Wisconsin.

Cooperative efforts between the Division of Forestry and the University of Wisconsin-Madison, Department of Forest and Wildlife Ecology, has led to the establishment of a joint 'tree improvement specialist' position currently funded on an annual basis. The university continues to employ faculty whose responsibilities include cooperation with state and federal agencies in forestry research and development activities, including tree improvement. This relationship is expected to continue. In addition, limited-term employees (LTE's) are utilized on an as-needed basis to accomplish specific time-dependent tree improvement program activities. This arrangement is expected to continue during the life of the current plan.

Facilities and Equipment

Nurseries

The Department currently operates three forest tree nurseries located at Boscobel, Wisconsin Rapids and Hayward, Wisconsin. Approximately 200 acres of irrigated land is available for seedling production within the state forest nurseries. This provides adequate capacity to accommodate the production and distribution of up to twenty-five million seedlings annually. Current nursery distribution has declined to the production of about 12 million seedlings annually, but production fluctuates with the availability of federal cost-sharing funds and the existence of other reforestation incentives.

Equipment

Heavy equipment for site preparation, planting, and maintenance is typically available to meet the needs of the program. Cooperation among the state nurseries, Department of Natural Resources (DNR), the University of Wisconsin, and other programs has been very good in terms of utilizing personnel and equipment for maintaining existing genetics program plantings. Some special equipment, especially for cone collection and breeding, has been rented on an as-needed basis. These arrangements are expected to continue.

Greenhouse

During the previous 10-years, the program has relied on University of Wisconsin-Madison campus greenhouses for all its propagation needs. Due to limited space and high demand, this has generally meant sharing space with other researchers and compromising on less than ideal conditions such as temperature and photoperiod. During late 2008, a new 1320 ft^2 greenhouse complex was added to the DNR Forest Health Lab at the Nevin Fish Hatchery in Fitchburg. This facility was designed to meet the specific needs of the Forest Genetics program as well as the DNR Forest Health Lab and will allow for increased efficiencies for both programs.

Genetics Testing Sites

At the present time approximately 201 acres of state and university land have dedicated Forest Genetics plantings (Table 1). These sites are distributed across the state and present a significant logistical challenge for coordination of pollen collection and breeding, and cone harvesting, processing and maintenance. Some older sites were located based on available land without regard to soil suitability. It would be very desirable to locate future seed orchards and breeding populations within the species natural range, yet near established DNR or state facilities, or the state nurseries, for administrative efficiency, maintenance and protection.

COUNTY	TOWNSHIP	AREA (ACRES)	SPECIES PLANTED
BAYFIELD	Bell	1.5	JACK PINE
CHIPPEWA	Anson	3	WHITE PINE
CRAWFORD	Haney	7	BLACK WALNUT, RED OAK
FOREST	Wabeno	6	WHITE SPRUCE
GRANT	Wyalusing	7	BLACK WALNUT
GREEN	New Glarus	1	BLACK WALNUT, RED OAK
IOWA	Pulaski	19	RED PINE, WHITE PINE
IOWA	Wyoming	2.2	EUROPEAN LARCH
JACKSON	Manchester	10	WHITE PINE
LACROSSE	Bangor	6	EUROPEAN LARCH, WHITE PINE
LANGLADE	Wolf River	9	EUROPEAN LARCH, WHITE PINE
MARATHON	Green Valley	6	WHITE SPRUCE
ONEIDA	Lake Tomahawk	36	RED PINE, WHITE PINE, WHITE SPRUCE
ONEIDA	Harshaw	10	JACK PINE
ONEIDA	Schoepke	2	JACK PINE
ONEIDA	Stella	6	JACK PINE
RICHLAND	Richwood	3	WHITE PINE
RUSK	Stubbs	1.5	JACK PINE
SAWYER	Lenroot	3	WHITE PINE
WASHBURN	Bashaw	22	WHITE PINE, WHITE SPRUCE
WASHBURN	Bass Lake	7.5	JACK PINE, WHITE SPRUCE
WAUSHARA	Hancock	10	JACK PINE
WOOD	Grand Rapids	1	WHITE PINE
WOOD	Saratoga	22	RED PINE, JACK PINE
	Total Acres	201.7	

Table 1. Listing by County and Township of WDNR Forest Genetics plantings currently under management in Wisconsin.

Budgets

Current budgets for the Department of Natural Resources tree improvement program provide for one half-time LTE assistant and support for one joint position in tree improvement split between the University of Wisconsin-Madison (10%) and the Department of Natural Resources (90%). In addition, we budget approximately $15,000 annually for supplies, travel and capital equipment. This budget has remained static save for small annual salary increases since the last tree improvement plan was completed in 1998. The budget also faces pressure from rising contract and travel costs. This current budget allows the program to be maintained at a flat or declining level but it cannot be expanded.

Future tree improvement budgets will need to account for expansion in plant materials collection (e.g., scionwood, seed collection), supplies, salaries and labor, travel and management and maintenance of test plantings. Any increase in the number of species included in the program, demands for nursery production above recent levels, or intensification of activities with individual species in the future, would require a concomitant increase in financial resources.

Partners

Forest Genetics is a specialized field posing unique challenges. Numerous individuals and agencies, both within and outside the Wisconsin DNR, are needed to assist with various phases of the tree improvement program. In addition to nursery personnel, staff from the Forest Health Program of the Division of Forestry has been especially prominent in supporting tree improvement efforts. Other technical assistance from outside sources includes:

1. USDA-Forest Service, Northern Forest Experiment Station. Geneticists and plant physiologists stationed at the Forest Sciences Lab, Rhinelander, Wisconsin, have provided both technical assistance and plant resources in the past but this relationship has declined as the Forest Service has relocated several genetics and tree improvement staff to the Hardwood Tree Improvement and Regeneration Center (HTIRC) at West Lafayette, IN. Despite this shift in personnel, HTIRC staff has provided technical assistance with grafting and have also provided genetics materials for testing.

2. USDA-Forest Service, Region 9, National Forest System. The geneticist assigned to the Oconto River Seed Orchard has been especially active in white pine blister rust-resistance screening and has provided the state with both assistance and plant materials. Continued cooperation is expected.

3. USDA-Forest Service, State and Private Forestry. A regional reforestation specialist based in St. Paul, MN provides technical assistance and some funding to state and industry tree improvement, nursery and reforestation efforts throughout the region.

4. University of Wisconsin-Madison, College of Agricultural and Life Sciences. Various faculty in Entomology, Forest and Wildlife Ecology, Plant Pathology and Soil Science have cooperated in the past on problems related to tree improvement, seed orchard management and forest nursery management. Such cooperation is expected to continue in the future.

5. University of Minnesota, Cloquet Forestry Center, Cloquet, Minnesota. Researchers with the Minnesota Tree Improvement Cooperative have collaborated on specific projects in the past and this is expected to continue.

6. Technical Committees. Members of the North Central Fine Hardwoods Tree Improvement Cooperative (NCFHTIC) provide valuable technical and educational assistance to tree improvement programs throughout the region.

7. USDA- Forest Service Hardwood Tree Improvement and Regeneration Center at Purdue University, West Lafayette, Indiana. Researchers here have collaborated on hardwood projects and provided technical assistance and this is expected to continue..

8. Other cooperators. Technical assistance is also available from other state forestry programs and forestry cooperatives within the North Central region that have established tree improvement programs.

9. Wisconsin Initiative on Climate Change Impacts (WICCI). This joint research group between the University of Wisconsin and Department of Natural Resources is expected to provide assistance in using forest genetics principles and data to assess climate change impacts on selected tree species in the future.

Program Emphases

Influencing Factors

A variety of factors influence the species and priorities emphasized in a forest genetics program. Most of these relate to the goals of the Division of Forestry and the genetic endowments of individual species. They include:

Reforestation

The ultimate product of any forest genetics program is planting material, either seed or vegetative propagules. Plantations are established for several reasons, and reforestation via planting remains an important but oftentimes secondary reforestation activity of federal, state and county agencies, forest industries, and many private individuals. The present and projected planting needs of these groups determine the amount of planting stock needed and also helps determine the magnitude of needed tree improvement activities.

Past demand for planting stock is one indication of reforestation needs, and good information on previous nursery stock production is available for Wisconsin. However, future demands may vary for several reasons including the availability of vacant land, federal cost-sharing funds for reforestation, tax incentives, the cost of plantation establishment and expectations regarding the future value of forest commodities. In Wisconsin, demand for planting stock from state forest nurseries has been declining during the past decade and now averages between 12-14 million trees per year (Figure 1). Two-thirds of this nursery production goes to private non-industrial forest landowners, with the remainder divided between county, state, and industrial users. In recent years, the forest products industry and especially paper companies have reduced their planting activities as industrial timber lands have been sold to other groups of investors.

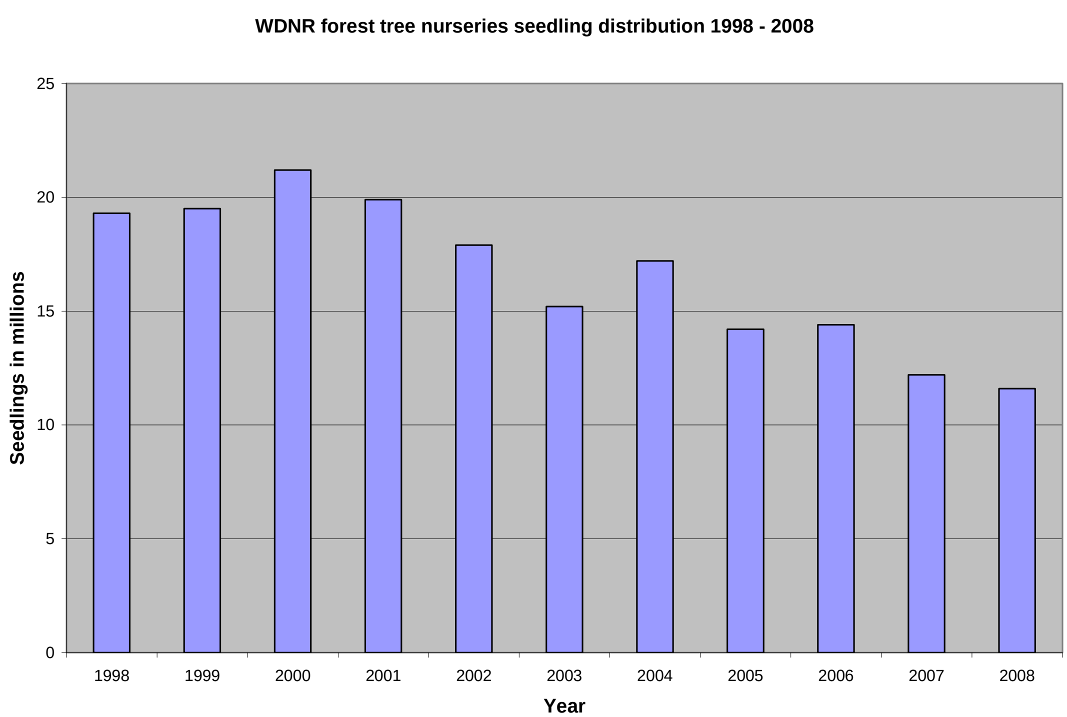


Figure 1. Seedling distribution summary from Wisconsin state forest nurseries, 1998-2008.

Current nursery stock demand projections suggest a slight upward trend in demand, to between 13-17 million seedlings a year through 2013. These demand projections are subject to change if new reforestation incentive programs are initiated for private non-industrial forest landowners, especially at the federal level (e.g., renewal of the Conservation Reserve Program). Planting trees on former agricultural land remains a dynamic issue with much current discussion centered on the possible supply and demand for biofuel feedstocks.

Biological and Genetic Potential

Opportunities for significantly improving the quality and growth potential of forest trees depend upon the biological and genetic characteristics of individual species. Differences in reproductive habit and fecundity, ease of propagation, levels of genetic variability contained within natural populations and other factors have considerable impact upon the potential for genetic gain within a species. In addition, the value of genetically improved trees to forestry activities in Wisconsin, the anticipated levels of genetic gain that could be obtained in the near future, and conservation threats to species are important factors to consider in assigning species emphases.

The principal tree species grown by the state forest nurseries were evaluated in the past according to their potential for yielding significant genetic gains, and the likely impact of these gains, on a state reforestation program. Certain aspects of these assessments involve qualitative judgments based upon limited information from early results of provenance and progeny tests. Perceived biological potential together with estimates of demand for reforestation provide a reasonable basis for assigning species emphases for tree improvement efforts in Wisconsin.

Species Threats

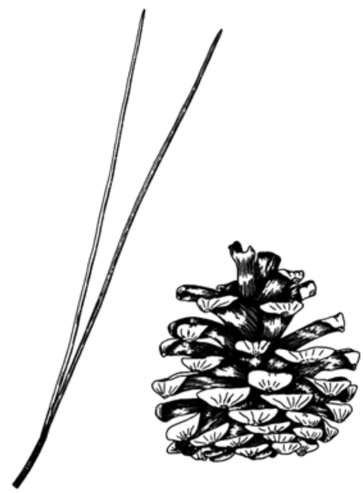
From the perspective of conserving genetic resources, it is also imperative that threats to certain tree species be evaluated in terms of need for assisted conservation. Global trade has increased the number of exotic pests that damage trees and their rate of spread throughout North America. “Old” pest problems such as Chestnut Blight (Cryphonectria parasitica) and Dutch Elm Disease (Ophiostoma ulmi) have been replaced in recent decades by newly introduced pests, including Emerald Ash Borer (Agrilus planipennis), Asian Long-horned Beetle (Anoplophora glabripennis), Butternut Canker (Sirococcus clavigignenti-juglandacearum), Hemlock Wooly Adelgid (*Adelges tsugae*) and others which have already devastated certain species, or have the potential to do so. Furthermore, some boreal forest tree species currently at their southern limit in Wisconsin may be at risk of extirpation should some climate change predictions prove true. The immediacy of threats, likelihood of reintroduction, biological factors influencing propagation and levels of genetic diversity are all factors that influence our ranking of species for conservation.

Historical, Ecological and Climate Factors

Wisconsin is divided into two diverse floristic regions, a ‘southern province’ dominated by oak-hickory, mixed hardwoods, and floodplain forests, and a ‘northern province’ dominated by coniferous forests with a large northern hardwood element present in many areas (Curtis, 1959). Some tree species such as black walnut have distributions confined to only a portion of the state while others such as red oak are more widely distributed. To satisfy the unique needs of different forestry interest groups in Wisconsin (e.g., hardwood lumber industry versus conifer pulp industry versus wildlife habitat interests), work with multiple species has to be conducted simultaneously. However, given a situation of limited resources, only a small number of species can receive substantial emphasis at any one time, and work with other species will have to proceed at a less intensive level.

Red pine, white pine, jack pine and white spruce have dominated planting stock demand during the recent past. Collectively, they represent 80% or more of distributed seedlings during the past few decades. Reforestation trends point to a future increase in demand for eastern white pine and jack pine, and perhaps white spruce, with a subsequent decrease in red pine seedling demand. This situation results from an increased reliance on natural regeneration for some species and a reduction, particularly by forest industry, in the acreage dedicated to red pine plantations. In addition, there has been a large increase in the utilization of hardwood tree species for reforestation in Wisconsin during the previous fifteen years, mainly due to concerns regarding species diversity and the creation of the federal Conservation Reserve Program which emphasized hardwood reforestation on former agricultural lands.

Species for Improvement



Red Pine

Potential

Historically, red pine has been the principal conifer used for reforestation purposes in the north central United States. Red pine has the reputation that it does not regenerate well naturally, but its ease of planting, excellent form and productivity on pine sites has made it a preferred artificial reforestation species. The state forest nurseries in Wisconsin currently produce 4 million red pine seedlings annually for distribution to public agencies, forest industry and private landowners.

From a genetic standpoint, red pine is an anomaly among pines in possessing comparatively little genetic variation (Moessler et al., 1992). Recent studies using microsatellite markers reveal that red pine contains low but detectable levels of molecular variation (Boys et al., 2005). Results of provenance studies indicate that small, though significant, differences in growth rate can be detected among red pine seed sources, but the range of genetic variation observed is much less than that found in other pines (Lester and Barr, 1965; Fowler and Lester, 1970; Wright, et al., 1972; Ager et al., 1982). Tree improvement and breeding efforts with red pine are somewhat controversial because of the obvious restriction of potential genetic gain. However, the extensive red pine reforestation program in Wisconsin, and concomitant seed requirement, led to the development of a red pine tree improvement program in Wisconsin beginning in 1965. The basic justification for this program is that even small genetic gains, when applied through large reforestation programs, have substantial cumulative benefits (St. Clair, 1984; Stier, 1988a, b).

Present program

A tree improvement program for red pine based on the seedling seed orchard approach was initiated in Wisconsin beginning in 1965 (Lester, 1965). Utilizing open-pollinated seed collected from 310 "mother trees" from throughout Wisconsin, three 15-acre seedling seed orchards were established in 1970 near Avoca (Iowa County), Ten Mile Creek (Wood County), and Lake Tomahawk (Oneida County). A limited amount of seed has been collected from the Avoca, Lake Tomahawk and Ten Mile Creek seed orchards during the past decade, and more seed could be collected here if seasonal labor and improved seed harvesting techniques were available.

The current seed orchards were established at a north, central, and southern location to provide seed for the 3 state forest nurseries in the event that subdivision of the state into separate breeding zones was required. Current information indicates that this is unnecessary and that Wisconsin can be considered one breeding zone or seed zone for red pine (Ager et al., 1982). Seed from future seed crops in these orchards could be used at all state nurseries with little risk of growth loss or adaptability concerns. This situation provides program flexibility by allowing inclusion of genotypes from all three seedling seed orchards to be used in future breeding work. Following several thinnings, these seed orchards now retain the "best" individuals of the "best" families based upon height and volume estimates.

The ‘best’ individuals from within the tallest 125 families in each orchard were identified during 2003-04 using diameter measurements (in lieu of height – the trees are now 50-60 feet tall) and stem form ratings. Open-pollinated seed has been collected from almost all selected trees and will be used to create one or more new seed orchards to serve the entire state.

Available Plant Materials

The DNR seed orchards currently contain families originating from throughout Wisconsin. In addition to the materials included in the present DNR seedling seed orchards, the following are sources of potentially useful red pine:

1. Several seedling seed orchards similar to those in Wisconsin were established in Michigan during 1964-65 using seed collected from both Upper and Lower Peninsula Michigan. Some Michigan seed sources performed well in earlier provenance tests (Wright et al., 1972), suggesting that future exchange of red pine with Michigan would be useful.

2. Several provenance tests of red pine in the Lake States region established during 1962-64 may provide useful genetic resources.

3. Several seedling seed orchards established by members of the Minnesota Tree Improvement Cooperative during 1980-81, including two on forest industry lands in Wisconsin, could provide materials of potential value to Wisconsin's program.

Traits to Improve

At the present time, growth rate is the only character that has received attention. Negligible amounts of genetic variation in wood specific gravity make improvement of wood quality unattractive (Ager et al., 1982). Also, in screening trials for disease resistance to *Scleroderis*, red pine progenies appear uniformly susceptible (Skilling, 1984). Given the inherently low rates of genetic variation found in red pine, efforts to identify genetic tolerance or resistance to native or exotic pests would probably yield few positive results.

Seed Production

Infrequent flower crops in natural stands of red pine pose a problem for seed procurement that may be partly solved in seed orchard settings with regular applications of nitrogen fertilizer (Lee et al., 1992). In addition, pesticide applications are invaluable in protecting cone crops from flower initiation to cone harvest (Rush et al., 1987; Katovich and Kulman, 1987).

Spacing has a large effect on flower and cone production, with wider spacing yielding larger crops (Stiell, 1971; Overton and Johnson, 1984; Stiell, 1988). At eighteen years of age, trees less than 5 inches DBH seldom produced cones, while trees in the 8-10 inch DBH classes yielded between 50-450 cones/tree depending upon spacing. Assuming an average seed yield of 25 seed per cone, 52,000 seed per lb. (Krugman and Jenkinson, 1974), one acre of trees at 21' x 21' spacing should yield about 15 lbs. of seed. However, such production could not be expected on an annual basis for red pine, and even with recommended cultural practices, good cone crops could be expected only once every 2-3 years. In addition, cone and seed insects will likely reduce yields (perhaps as much as 25%) even with approved pest control measures. A more realistic expectation may be 10 lbs. of seed per acre during a good seed year (Mattson, 1976; 1978).

At the present time the state forest nurseries sow about 33 lbs. of red pine seed per million seedlings produced (Marty, unpublished data). This equates to an annual need for 132 pounds of red pine seed for the state nurseries.

The present seedling seed orchards are 28-years old (from seed) and are capable of producing significant crops of seed (the Avoca seed orchard has produced small quantities of seed during the past decade). But even with moderate levels of seed production from the present red pine seed orchards there would be a seed shortfall each year. In addition, collecting the seed actually produced by the seed orchards is a major limiting factor that prevents taking full advantage of improvement efforts with red pine.

Future Program

In the future, we expect to overcome the high cost of collecting seed from large trees by managing smaller, height controlled orchards through pollarding. The families to be used in future seed orchards will be selected from the best individuals of the best 125 families from each seed orchard, thereby retaining a broad genetic base. It is also anticipated that new and well managed orchards could supply enough seed to eliminate the need for general collections from wild stands.

In the interim, seed orchard collections will be supplemented by collecting seed from the best local Wisconsin stands with the understanding that subsequent seedlings would be distributed near the collection site.

Schedule

2009	Finish Open Pollinated Seed collection	**2014**	Maintain new plantings
2010	Extract Open Pollinated Seed and select second generation Orchard sites	**2015**	Close Avoca seed orchard
2011	Sow second generation seed in greenhouse and site prepare field sites. Transplant seedlings to nursery beds	**2016**	Measure height on new plantings. Close Lake Tomahawk seed orchard
2012	Plant field sites and measure survival	**2017**	Close Ten Mile Seed orchard
2013	Maintain new plantings	**2018**	Measure height on new plantings

Species for Improvement

Jack Pine

Potential

Jack pine is one of the most widely distributed conifers in Wisconsin. Historically, regeneration was almost exclusively by natural means or by direct seeding. Recently, establishment of jack pine plantations has increased substantially, in part due to conservation programs, with state nursery production in Wisconsin currently about 1,500,000 seedlings per year during the past decade. However, the overall acreage of jack pine type in Wisconsin is decreasing due to species conversion and development.

Jack pine is characterized by large amounts of genetic variation for many traits of interest including growth rate, stem form, wood specific gravity (Edge, 1991; Rudolph and Yeatman, 1982). Opportunities for genetic improvement in these traits are exceptionally good in jack pine, given its precocious flowering habit, regular cone crops, and adaptability to a wide range of sites. Major constraints to more widespread use of jack pine are pest problems, especially jack pine budworm (*Choristoneura pinus*), and pine-oak gall rust (*Cronartium quercum).*

Present program

1. Since 1990, the state nurseries have sown jack pine seed collected almost exclusively from first generation seedling seed orchards. Estimates of expected genetic gain in height growth rate range between 11-15% (Edge, 1991). Selection within these first generation seed orchards has emphasized volume growth, resistance to pine-oak gall rust, stem form, branch angle and crown characteristics.

2. In 1980, the Bureau of Forestry established two jack pine "breeding populations" as part of a coordinated testing and breeding scheme organized by the USDA-Forest Service, Forestry Sciences Lab, Rhinelander, WI (Riemenschneider, 1979). Breeding populations are located at Bean Brook Fishery Area (Washburn County) and Ten Mile Creek Seed Orchard Complex (Wood County). Each of these breeding populations contains twenty families, from Wisconsin, Minnesota and Michigan planted in twelve replications of four-tree row plots per replication. A 1.5-acre second-generation breeding population (Ten Mile III) was created using controlled crosses of parents drawn from families at Ten Mile Creek and Bean Brook and out planted at the Ten Mile Creek Seed Orchard Complex in 1999. The original Ten

Mile first-generation breeding population was removed in 2004 due to declining stand health.

As a part of the coordinated testing and breeding scheme, the University of Wisconsin-Madison, Department of Forest and Wildlife Ecology, established four 'research and breeding' populations in 1980 at the Hancock Research Station (Waushara County) to provide a research framework for genetic studies. Each population contains twenty families from Wisconsin, Michigan and Minnesota in four-tree row plots with twelve replications (identical to the 'breeding populations' except for the inclusion of different families). Research with these populations confirmed the high levels of variation noted in earlier provenance and progeny tests. Estimates of genetic gain for growth rate range from 11-15% following selection of the best individuals of the best families to serve as parents; additional improvement in stem and crown form may be just as great (Edge, 1991). These plantings were rogued to final seed orchard densities in 1990.

In 1996, a 6-acre second-generation breeding population, created with controlled crosses amongst the best individuals within families at the Hancock research populations, was out planted at the Ten Mile Creek Seed Orchard Complex. This planting (Ten Mile II) also contains twelve replications with four-tree row plots per replication. In 2006, the two smallest trees in each four-tree plot were removed to promote crown development and seed production. Prior to this, controlled crosses amongst the best individuals within each family, with added attention to pine-oak gall rust (*Cronartium quercum)* resistance, were made and will be used to create a third-generation seed orchard on the Black River Falls State Forest (Jackson County).

3. A 6-acre USFS progeny test at Harshaw (Oneida County) containing 101 families and 9 bulk collections was rogued to create a seed orchard in 1984. Seed has been collected from this orchard periodically since 1986 for use in Wisconsin's reforestation program.

4. A 5-acre, second-generation seed orchard consisting of 33 families was planted at the Greenwood Wildlife Area (Waushara County) in 1997. The material consisted of selections made from single pair controlled crosses between top individuals at four breeding populations (Ten Mile, Monico, Bean Brook, Ashland) and the Hancock research populations. The planting was rogued in 2005 and has been supplying seed to the state nurseries since 2006.

5. A 2-acre, second-generation breeding population was established near Ladysmith (Rusk County) in 1996 in collaboration with Consolidated Papers and the DNR. The planting consists of 22 families produced through controlled crosses between the best individuals at Consolidated Papers Ashland seed orchard. This seed orchard was generated using open-pollinated seed collections from native tree stands in Wisconsin, Minnesota and Michigan. Unfortunately, a large number of the trees were damaged by extreme winds in 1999 and 2002. As a result, much of the material is in poor or declining condition. In addition, this forest industry property has changed ownership numerous times. A breeding effort was begun in 2006 to carry forward the families via controlled crosses between the best individuals in each family to produce a 3rd generation population.

Available Plant Materials

A large array of jack pine genetic resources within Wisconsin and the Lake States region is available for tree improvement and breeding activities. In addition to the breeding populations, research population and seed orchards noted earlier the following materials also are available:

1. A number of provenance tests (including both regional and range-wide collections) established by the

USDA-Forest Service are located in 9 different counties. Numerous family tests established by the USDA-Forest Service in Ashland, Oconto, Oneida, and Vilas Counties between 1966 and 1980 are also available;

2. Several breeding and research populations established by the Forestry Sciences Lab, Rhinelander, WI, and distributed to federal, state, university and industrial cooperators in the Lake States region during 1979-80 are also available;

The most valuable materials are those directly controlled by the WDNR and the University. Despite the large volume of materials controlled by the Forest Service and other cooperators, their value diminishes over time as test sites age, scientists retire and die and records are lost.

Traits to Improve

Work focusing upon growth rate, gall rust resistance, stem form, wood specific gravity and crown form will continue. Adaptability appears not to be a concern if we restrict our attention to Wisconsin, southern Minnesota, and Michigan seed sources; Wisconsin will be considered a single breeding zone for this plan. Considerable amounts of genetic variation exist for traits under consideration, although some traits (e.g., resistance to certain pests) would require considerable (and expensive) testing to yield predictable levels of improvement. Appreciable levels of improvement appear possible within a few generations using relatively low cost methods of selection and breeding.

Seed Production

Some cones are produced in jack pine almost every year, with good cone crops produced every 3-4 years. As with other conifers, however, a number of cone and seed insects can substantially reduce yields (Rauf et al., 1981; Rauf et al., 1985; Marty, personal observation). Cone and ovule abortion are also continuing problems which reduce potential seed yields.

Several studies of cone and seed yield have indicated that large volumes of seed are produced at fairly young ages in jack pine. Jeffers (1975) estimated that seedling seed orchard production could average 108,000 seed/acre/year by age 6, while Rudolph (1977) estimated total yields by age 6 to be greater than 119,000 seed/acre; by age 8, yields were projected to increase to 655,000 seed/acre/year. Both studies assumed that cones contain approximately 25 full seed.

The present nursery seed requirement for jack pine is about twenty-seven pounds of seed to produce 1,750,000 seedlings per year (Marty, unpublished data). As there are approximately 120,000 seed per pound (Krugman and Jenkinson, 1974), 8 acres of seed orchard (by age 8) would satisfy annual nursery needs.

Future Program

In the near future, establishment of a third-generation seed orchard on the Black River Falls State Forest (Jackson County) planned for 2011 together with existing young seed orchards in Wood and Washburn counties will provide sufficient seed to meet WDNR requirements for jack pine. Improvement activities will continue with subsequent generations being grown and earlier orchards taken out of production.

The genetic materials contained within the program are also of value from a conservation standpoint as jack pine is diminishing on the landscape. Jack pine may also be a species at risk from climate change. Maintaining a broad base of widely adapted genotypes will help ensures our ability to regenerate jack pine on the landscape in the future.

Schedule

2009	Controlled crosses at Ladysmith, Ten Mile II and III orchards. Rogue Ten Mile II and Greenwood orchards. Collect 2008 controlled crosses	**2014**	Plant Ten Mile III third-generation orchard. Measure 2-year heights at Ladysmith third-generation orchard and close Bean Brook orchard.
2010	Extract and Sow controlled crosses from 2008 and pollinate crosses at Ladysmith and Ten Mile III. Site prepare and fence Black River Falls planting site	**2015**	Measure 2-year heights at Ten Mile III third-generation orchard and close Ladysmith orchard
2011	Plant and check survival on the Black River Falls site. Select site for Ladysmith third generation planting. Pollinate Ten Mile III controlled crosses	**2016**	Measure 5-year heights Black River Falls
2012	Extract and sow 2010 crosses. Prepare and fence Ladysmith third-generation planting site.	**2017**	Measure 5-year heights Ladysmith third generation orchard
2013	Extract and sow 2011 crosses. Plant Ladysmith third-generation. Measure 2-year height at Black River Falls. Close Hancock breeding population	**2018**	Measure 5-year heights Ten Mile III third-generation orchard

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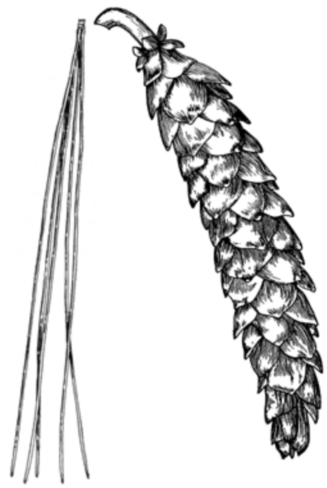
Species for Improvement



Eastern White Pine

Potential

Eastern white pine is the second most common tree grown in the state nurseries today, with an annual production of approximately three and one-half million seedlings. Demand for seedlings would likely increase if seedlings tolerant to white pine blister rust (*Cronartium ribicola*) were available, or if landowners were convinced that silvicultural practices could minimize the impact of blister rust (Van Arsdel, 1968; Figure 2). White pine blister rust continues to be a problem in northern and central WI where populations of the alternate host, (*Ribes* spp.) are abundant along riparian zones and on mesic soils. White pine grows well on a variety of sites in Wisconsin, but is most closely associated with sandy or loamy-sand soils where hardwood competition is reduced and where a natural succession to white pine is occurring. White pine can be regenerated naturally, with shelterwoods being the preferred silvicultural system to minimize the impact of white pine weevil (*Pissodes strobi*).

Several provenance/progeny tests with eastern white pine in the eastern United States have provided only limited information on seed source differences useful in Wisconsin. As a general rule, seed from stands in the southern Appalachians is recommended for planting in most of the eastern U. S., as southern Appalachian seed sources have proven to be faster growing than most local sources in many tests (Wright et al., 1976). However, this superiority declines (or is reversed) based on information from small tests in Iowa and northern Wisconsin (King and Nienstaedt, 1968; Nienstaedt and King, 1968).

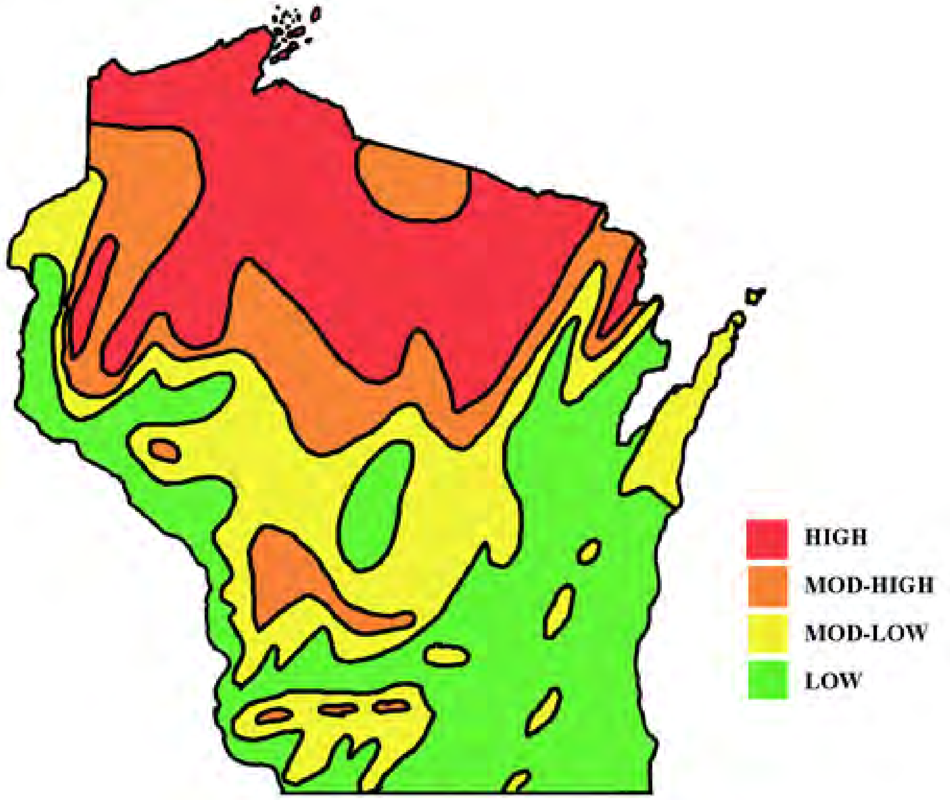


Figure 2. The potential for white pine blister rust damage in Wisconsin (after Van Arsdel, 1968)

Results from a limited Wisconsin trial indicate that eastern white pine from southern Appalachian seed sources will survive in Wisconsin, but superior growth is only evident in southwest Wisconsin (Figure 3). Seed sources from the southern Appalachians are no better than, and usually worse than, local nursery stock of local seed sources. We do not recommend planting southern seed sources of eastern white pine north of a line between Eau Claire-Wisconsin Rapids-Sheboygan (Edge et al., 1991; Monk et al, 1998a).

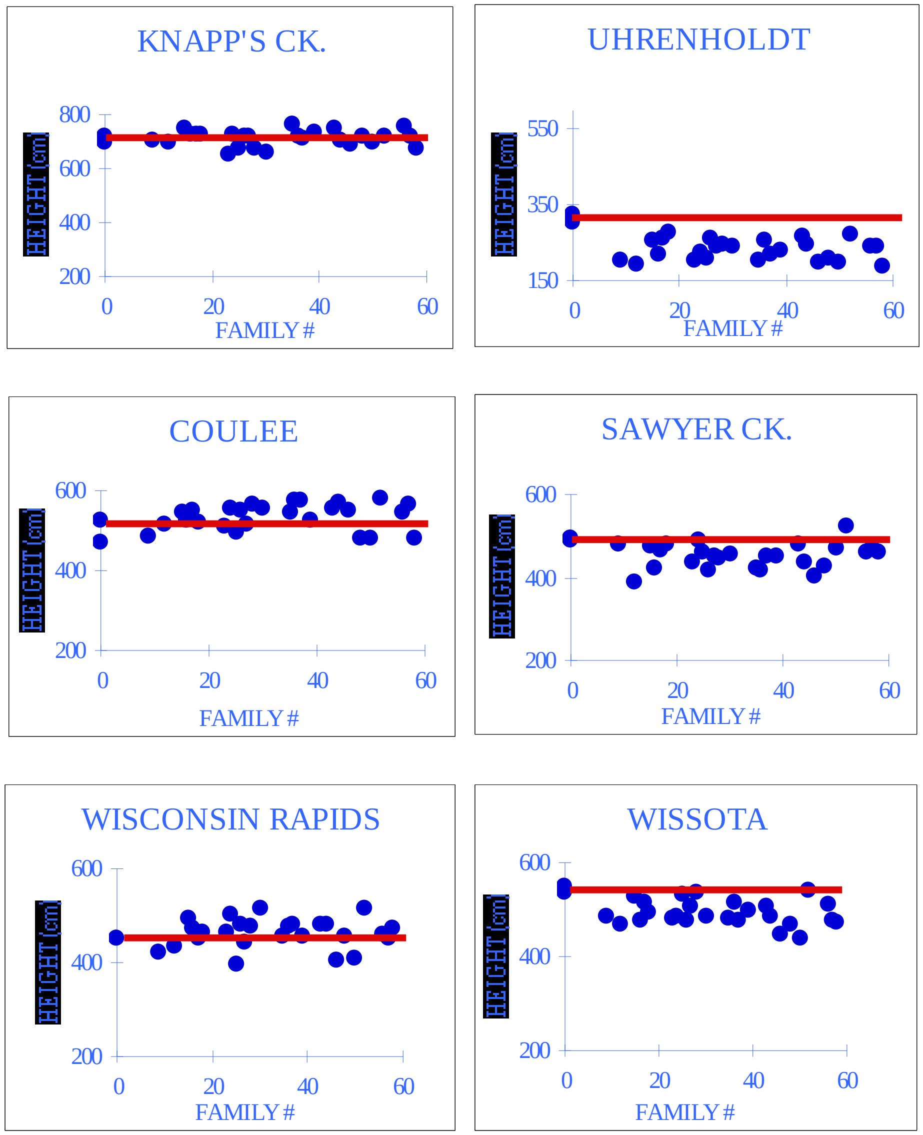


Figure bb. Performance of southern Appalachia eastern white pine seed sources at several sites in Wisconsin. The red line represents the average of nursery run seedlings at each site.

Present program

1. A small planting of one North Carolina seed source was established in Iowa County during 1981 together with ‘nursery run’ seedlings from Wisconsin. Results from this test suggest that North Carolina seed sources may provide increased height growth in southern Wisconsin.

2. The University of Tennessee provided white pine seed from 48 individual tree collections and 10 bulk collections from southern Appalachian sources. Observations of survival and growth of these sources made at six Wisconsin locations beginning in 1986 (Edge et al., 1991) indicate that southern Appalachian white pine seed sources experience severe ‘needle burn’ of the foliage during most winters. We believe this occurs because needles on the southern Appalachian sources remain "splayed out" from the stem exposing greater surface area to drying winter winds. Local Wisconsin sources appear to have an adaptive advantage in that the needles during the winter "lay down" against the stem (Marty, personnel

observation).

3. Beginning in 1983, through a cooperative effort with the USDA-Forest Service, grafts of putative blister rust-resistant eastern white pine were obtained and planted within a ten-acre clonal seed orchard at the Sawyer Creek Fishery Area (Washburn County). Trees are now producing seed and a total of 81 lbs of seed was collected in 2007, with an even larger crop (292 lbs.) collected in 2008. An ‘informal’ progeny test of white pine seedlings produced from this seed orchard was established at the Sawyer Creek Fishery Area in 1994 and 1995 to evaluate the level of rust resistance in this material. One clone was eliminated from the seed orchard based on seedling performance in this test. Additionally, material in this orchard are being re-evaluated for blister rust resistance by the USDA-Forest Service and new progeny tests are being used to better evaluate growth and form. Increasing quantities of seed have been collected from this orchard since 1990 for use by the state nurseries.
4. Information on the extent and patterning of genetic variation in Wisconsin’s eastern white pine populations will be obtained from two provenance/family tests established during 2002-2003. Cones from 234 trees representing 50 natural stands of eastern white pine were collected across Wisconsin during 1996-2000. In addition, USDA-Forest Service provided seed from 142 selections made in the Upper Peninsula of Michigan, Minnesota, and Wisconsin. From these collections, a “northern” white pine test was established on a 14-acre site in the Northern Highland-American Legion State Forest near Lake Tomahawk (Oneida County) in 2002. This test includes 256 families planted in 4-tree plots replicated in 10 blocks. In the spring of 2003, a second set of seedlings was planted on a 10-acre site in the Black River State Forest (Jackson County) to create a “southern” Wisconsin test. This planting contains 248 families planted in 4-tree plots in 8 blocks. The short-term benefit of this research will be the identification of eastern white pine seed sources well adapted for use in Wisconsin reforestation efforts; the long-term benefits will be the development of two seedling seed orchards for future seed production and genetic resource conservation of Lake States white pine.

Available Plant Materials

With the exception of materials controlled by the USDA-Forest Service at their Oconto River Seed Orchard, white pine materials of known genetic origin are almost non-existent in Wisconsin. The only provenance test, a 2.5 acre planting established by the U.S. Forest Service in 1962, contains trees from 17 sources throughout the range of eastern white pine. Most of these sources have proven to be inferior to local Wisconsin sources. As such, the 2002-2003 tests of the Lake States sources will help to increase the diversity of white pine being evaluated in the state

Traits to Improve

Breeding disease resistant trees is a lengthy and expensive process with no guarantee of long-term success. Appropriate silvicultural practices can minimize the impact of diseases such as blister rust in many areas, but disease tolerance/resistance offers the best prospect for reforestation with white pine in high hazard areas; e.g., *Ribes* eradication has simply not worked. For high-hazard areas, the USDA-Forest Service efforts in screening and breeding blister rust resistant white pine offers the best prospect for producing improved materials. However, the Forest Service selections were made without regard for growth-related traits so a separate program which includes traits other than blister rust appears warranted for low hazard areas which constitute most of Wisconsin. Given the high levels of stand-to-stand genetic variation in white pine, the potential for appreciable increases in growth rate appears very good.

Another perceived problem with white pine reforestation is white pine weevil (*Pissodes strobi* (Peck)), but a number of studies in the eastern US seeking evidence of genetic resistance to weevils have been inconclusive. However, good silvicultural practices – especially the use of shelterwood regeneration systems - appear capable of minimizing this problem. Given the availability of silvicultural control measures and the rapid growth rate of white pine, this program will focus on improving growth and form, while eliminating individuals and families overly susceptible to blister rust infection.

Seed Production

Flowering and cone production in eastern white pine is somewhat sporadic and, while some trees may produce a good cone crop every 2-4 years, other trees (and stands) may produce few cones over many years. For example, at the Oconto River Seed Orchard, fewer than 31 percent of the white pine grafts flowered even once during the first 7 years after establishment (Murphy and Miller, 1979). In addition, significant flower production may not occur for 15-20 years from seed, with male flowers in short supply on young trees. Thus, seed orchard development with white pine is truly a long-term proposition.

Our long-term investment is being realized at the Sawyer Creek seed orchard, which is providing enough seed to meet nursery demand for high hazard areas. This will provide interim seed while the two newer plantings grow to production age. At that time, our focus will change to further improving seed quality as volume demands are met.

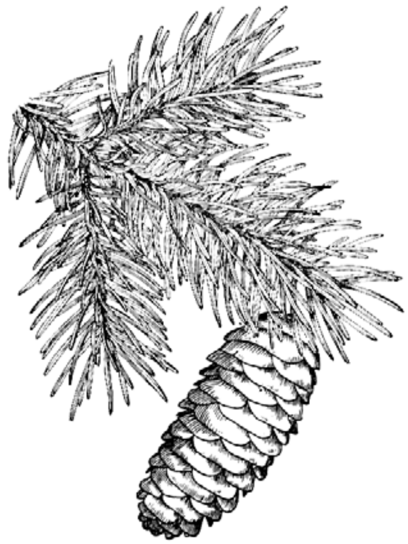
Future Program

Two activities will dominate our white pine program during the next several years: (1) continued evaluation of the current provenance tests at Lake Tomahawk and Black River Falls, especially for growth related traits; and (2) continued cooperation with the US Forest Service blister rust screening program at Oconto River Seed Orchard. Both of these activities will help provide sources of genetic materials and seed for future nursery needs, but neither will contribute large quantities of seed in the near term.

Schedule

2009	Blister Rust Scoring at Black River Falls and take Lake Tomahawk 8-year measurements	**2014**	Graft Scion from MN and USFS. Outplant resistant grafts. Dig grafting rootstock
2010	Thin Sawyer Creek II Blister Rust Progeny. Black River Falls 8-year measurements	**2015**	Graft Scion from MN and USFS
2011	Thin Knapp's Creek. Measure Lake Tomahawk 10-year measurements	**2016**	Outplant grafts and take 15-year measurements at Lake Tomahawk. Close appalachian trials
2012	Thin Sawyer Creek III Blister Rust Progeny. Measure Black River Falls 10-year measurements. Dig grafting rootstock	**2017**	Outplant grafts. Take 15-year measurements at Black River Falls
2013	Graft Scion from MN and USFS. Dig grafting rootstock	**2018**	Mark Lake Tomahawk for Rogueing

Species for Improvement



White Spruce

Potential

Approximately two million white spruce seedlings are distributed each year from Wisconsin's state forest nurseries, and this level of production is expected to increase slightly in the future. White spruce is relatively demanding in site requirements, attaining its best growth on podzolized loams and clays while faring poorly on sands. Natural regeneration can be obtained if measures are taken to control weeds and brush, as white spruce seedlings are slow growing during their first several years.

White spruce possesses considerable genetic variation for a number of traits including growth rate, wood specific gravity, branch angle and several other characters (Nienstaedt and Teich, 1972). The potential for genetic improvement in white spruce is excellent and breeding materials are available from several tree improvement programs in the Lake States region.

Present program

1. A seedling seed orchard comprised of 175 families representing materials from Ottawa Valley, Ontario, and selections from the Lake States region made by the USDA-Forest Service, was established at the Mead Wildlife Area (Marathon County) in 1982. The shortest 30% of this population was thinned out in 2007 based on 1997 height data while preserving the best individuals from all families. This will allow for greater access into the orchard for future cone harvests, as well as improve crown development. Seed has been collected from this orchard since 2002 for use by the state nurseries. Superior parents identified within the planting will be incorporated into a grafting program to expand future clonal seed orchards.

2. A 10-acre progeny test comprised of selected materials from 168 different families from throughout the Lake States region and the Ottawa Valley was established at the Sawyer Creek Fishery Area in 1989. Based on seventeen-year height and diameter measurements, 58% of the planting was removed in 2008-9 while preserving the best individuals from all families. This will improve crown development for

increased seed production and facilitate seed collection efforts. Superior parents identified within the planting will be incorporated into a grafting program to expand future clonal seed orchards.

3. A cooperative agreement between the Wisconsin DNR and the USDA-Forest Service provides access to progeny tests of diverse white spruce materials established by the Forest Service in 1969 at Lake Tomahawk (Oneida County) and Wabeno (Forest County). These 6-acre progeny tests originally included ninety-two families; the planting at Lake Tomahawk was rogued to the best 25% of initial families in 1987 to create a seedling seed orchard. This orchard has produced significant quantities of seed for the state nursery program since 1987 but is nearing the end of its useful life. Expected genetic gain for height growth is estimated at 15%-20% for seedlings produced from this seed orchard (D. Riemenschneider, personnel communication). Superior parents identified within the planting will be incorporated into a grafting program to expand future clonal seed orchards.

4. Approximately 6 acres of seedling seed orchard, including 4500 ‘super seedlings’ (Nienstaedt, 1981), were established at Bean Brook Wildlife Area (Washburn County) in 1977-79. ‘Super seedlings’ were selected on the basis of height growth in state forest nursery seedbeds. This planting, initially thinned in 1987 has been providing only limited seed to the nursery program since the Mead planting began production.

Available Plant Materials

As a result of studies initiated by Dr. Hans Nienstaedt, formerly with the Forestry Sciences Lab, Rhinelander, Wisconsin, significant collections of white spruce breeding materials exist in the Lake States region. These materials include:

1. The range-wide white spruce provenance collections maintained at several locations in Wisconsin, now about 40 years of age; materials from the Ottawa Valley are included here.

2. A number of tests of families of known parentage, including progeny selected on the basis of superior phenotype, are maintained at several state and federal sites in Wisconsin.

3. Clones now included in seed orchards, clone banks and clonal tests have been (or are being) progeny tested and are currently maintained by the U.S. Forest Service in Oconto and Oneida Counties.

4. The Minnesota Department of Natural Resources and Minnesota Tree Improvement Cooperative both have significant white spruce genetic resource collections that may be of future benefit to Wisconsin's program.

Traits to Improve

At the present time, growth rate is the only characteristic that receives attention; wood quality may be considered at a later date. Concern in the United States and Canada over losses of white spruce to spruce budworm (*Choristoneura fumiferana*) would make resistance to this pest an attractive component of a tree improvement program, but there is very little information on components of pest resistance in white spruce. Given the limited success at selecting and breeding trees for insect resistance elsewhere, an applied pest-resistance breeding program for white spruce in Wisconsin appears unrealistic at this time.

Seed Production

Heavy seed crops in white spruce occur every 2-6 years with light seed crops in between. Seed production may begin as early as 4-5 years of age, but modest levels of production usually are not obtained before 12-16 years; grafts of sexually mature scions appear to flower somewhat earlier. Cone production varies widely among trees (clones) with some mature individuals producing as many as 1,800 cones in a single year. Numbers of sound seed per cone vary depending upon weather conditions during pollination, fertilization and development, with 30 seeds being average (Safford, 1974).

Estimates of cone and seed yield from grafted white spruce seed orchards following a good flowering year were made by Nienstaedt and Jeffers (1970) for several different initial tree spacings. Nine years after grafting, trees averaged about 80 cones per tree with yields of filled seed per acre ranging from 102,652 (30' x 30' spacing) to 410,606 (15' x 15' spacing) under open-pollinated conditions. By age 20 or 25, cone production should increase 3 or 4-fold, with potential seed production ranging from 2-8 lbs./acre/year (assuming 226,000 seed/lb).

Estimates of seed yield in seedling seed orchards are based on our experience at the Lake Tomahawk Seed Orchard, Bean Brook Fishery Area and Mead Wildlife Area seedling seed orchards. In 1995, an average cone crop year, seed production at the Lake Tomahawk Seedling Seed Orchard (27 years of age) yielded four pounds of seed per acre, while the Mead Wildlife Area Seedling Seed Orchard (14 years of age) yielded 1.7 pounds of seed per acre (Marty and Borkenhagen, unpublished data).

Improved cultural practices could increase yields above the levels indicated, and grafted orchards would likely maintain their advantage in terms of time to first seed production. To maintain the current production of two million seedlings annually the state nurseries require about 35 pounds of seed/year. We anticipate that a total of 15-20 acres of grafted seed orchard would be required to completely satisfy the state nursery seed needs, and a slightly greater acreage would be required for seedling orchards. The current acreage of white spruce seed orchards would be sufficient to meet demand at this level, but new orchards are needed to replace aging orchards, e.g. Lake Tomahawk.

Future Program

Our most immediate need involves the creation of new grafted clonal seed orchards at 1-2 sites using best selections currently available in all plantings. Completion of the new greenhouse facilities at Nevin State Fish Hatchery will allow grafting to proceed more efficiently than was possible in the past.

Schedule

2009	Rogue Sawyer Creek and dig testing root stock	**2014**	Select and graft Sawyer Creek selections. Plant Lake Tomahawk grafted clones and close Bean Brook
2010	Test grafting techniques	**2015**	Plant Mead grafted clones and check survival on Lake Tomahawk. Close original Lake Tomahawk
2011	Collect and graft Lake Tomahawk selections. Select planting site at Lake Tomahawk	**2016**	Plant Saywer Creek grafted clones and check survival on Mead. Close original Mead site
2012	Collect and graft Mead selections. Select planting site at Mead	**2017**	Check Survival on Sawyer Creek
2013		**2018**	Measure Lake Tomahawk in 2019

Species for Improvement

Black Walnut

Potential

On an individual tree basis, black walnut is the most valuable species grown in Wisconsin. High quality sawlogs and veneer logs have always commanded premium prices while lesser-grade logs often sell for several hundred dollars per thousand board feet. During the past two decades, demand for black walnut planting stock has been a modest but steady 130,000-170,000 seedlings per year. This limited demand is the product of the limited range within Wisconsin where black walnut is hardy, as well as the limited number of suitable planting sites available.

Tree improvement activities with black walnut have centered on the Ohio River Valley and Southern Plains states (especially Indiana, Illinois, Iowa and Missouri), the heart of the commercial range of black walnut. Provenance and progeny test results indicate that southern seed sources, when moved as much a 200-300 miles north of their origin, can grow 10-15% faster than local sources (Bey, 1973a, b; Bey, 1980; Deneke et al., 1987; Bresnan et al., 1994). However, at the northern margin of the species range (including Wisconsin), winter injury to trees from sources moved more than 100 miles north of their origin is a concern (Bey, 1979; Deneke et al., 1980; Clausen, 1988). For example, a small test of black walnut from Indiana planted in Richland County in 1980 experienced significant mortality during the winter of 1982. Additionally, a collection of Indiana sources suffered significant mortality in the nursery at Boscobel, Wisconsin during the establishment of a family test/seedling seed orchard (Marty et al., 1987). This underscores the need for a conservative approach to the use of non-local sources of black walnut.

Present program

1. A five-acre family test/seedling seed orchard was established in Grant Co. in 1978 with 114 families from Wisconsin, southeast Minnesota, Indiana and northern Illinois. Data on growth and form characteristics from this planting have been used to establish seed purchasing zones for the state nurseries. Families originating in southern Wisconsin (Grant, Lafayette, and Iowa Counties) and northern Illinois are considered the best performers, while seed sources from Minnesota and southern Indiana appear poorly adapted to Wisconsin conditions (Marty et al, 1987; Monk et al, 1998b; Figure 8). No estimates of genetic gain were determined, but experience suggests a 3-5% increase in growth rate is possible. More

significantly, improved stem form, branch number and branch angle may be expected (Beineke, 1974; Beineke and Masters, 1973).

2 In 2004, a 10-acre sight was identified on the Kickapoo River Wildlife Area, Bell Center Unit (Crawford County) for a black walnut seed orchard. Starting in 2006, grafted clones of phenotypically superior black walnut from natural stands in Wisconsin and Northern Illinois have been out planted on the site with 100% survival. Learning from past planting failures, this site is surrounded by a 7.5-foot-tall fence to exclude deer intensive weed control. Surviving selections from the New Glarus Woods State Park (Green County) clone bank have been successfully grafted and are being out planted to this site. Additional clones will be added to the site over a number of years as new selections are made and grafts become available. The orchard serves both to conserve the limited genetic resource of black walnut that is adapted to Wisconsin and to provide future sources of improved seed for the state nursery program.

3. In 2007 a cooperative planting with the USDA –Forest Service Hardwood Tree Improvement and Regeneration Center (HTIRC), Wisconsin Walnut Council and Wisconsin DNR was established in Monroe County. The 1-acre planting consists of grafted clones from 12 elite families from HTIRC's advanced black walnut breeding material along with 3 superior Wisconsin clones, one F1 hybrid of *J. nigra* x *J. regia* and nursery run stock from Wisconsin and Indiana. This planting will be compared to similar plantings in S.W. Missouri, East Tennessee, Southwest Michigan, and Central Indiana to estimate the range in regional adaptability of these selections.

Available Plant Materials

Significant collections of black walnut genetic materials exist at the former USDA-Forest Service, Forest Sciences Lab, Carbondale, IL, and at several state agricultural experiment stations, but most of this material is of limited value in Wisconsin. Much of the material in these collections represents more southerly sources that would not be hardy in Wisconsin. The best source of additional materials for future improvement efforts in Wisconsin will be wild stands in the northwest part of the species range, including those represented in the present seed orchard.

Traits to Improve

Stem form and growth rate are the two traits of greatest interest in black walnut tree improvement. Stem form and growth rate are modified by site and environment and can also be improved via silvicultural practices, but work in Indiana and Illinois has demonstrated that selection for both characters can lead to increased performance (Beineke, 1974; Beineke and Masters, 1973). Resistance to certain pests (e.g., leaf anthracnose), increased nut production (for nursery buyers interested in nut as well as wood production) and certain wood quality traits could be included at a later date as need and budget permit.

Seed Production

The state nursery program currently utilizes one-half bushel of hulled seed per nursery bed to produce an average of 300 black walnut seedlings (Marty, unpublished data). Our annual production of 100,000 seedlings requires the purchase of approximately 167 bushels of hulled black walnut seed (617 bushels of un-hulled black walnut) each year; there are approximately 1,000 hulled nuts per bushel. Thus, our requirement of 167 bushels represents approximately 167,000 hulled nuts.

Seed production in black walnut can begin as early as age 5-8, but significant quantities of nuts are not produced before age 20. Good seed crops are produced every 3-4 years, with a typical crop yielding approximately 600 nuts on a 20-year-old tree (Beineke, personnel communication).

Given the long delay from planting to initiation of seed production, especially in seedling seed orchards, and the immediate and continuing need for seed by the nurseries, the possibility that ‘seed production areas’ could also satisfy some black walnut nursery demand is being considered. Several public and private forests, including Wyalusing State Park, the Hallock Demonstration Forest (Green County), the Rule Walnut Forest (Iowa County) and others, all contain high quality stands of black walnut and could provide the land base for ‘seed production areas’. This low cost source of seed, in combination with development of seed orchards, could satisfy most nursery needs in future years. However, it would be desirable to test the performance of seed from several stands before dedicating them as black walnut ‘seed production areas’. In the near term, this program will be focusing on identifying and developing ‘seed production areas’ and efficient collection techniques; development of a grafted seed orchard at Bell Center represents the long-term approach to satisfying seed needs.

Future Program

During the next five years, our tree improvement activities with black walnut will focus on (1) development of several ‘seed production areas’ in southern Wisconsin so that a reliable source of high quality seed can be obtained for the nurseries; and (2) continued grafting of scions of selected black walnut trees into a clone bank at Bell Center. We will continue to cooperate with staff from the HTIRC at Purdue to evaluate other plant materials that they may wish to evaluate here, but our emphasis will continue to be on ‘local’ sources of black walnut for reforestation purposes.

Schedule

2009	Collect, graft and outplant scions at Bell Center. Maintain HTIRC planting. Dig rootstock	**2014**	Collect seed and maintain collection sites
2010	Select 3- 5 collection areas on state lands. Plant grafts at Bell Center	**2015**	Collect seed and maintain collection sites
2011	Plant grafts at Bell Center	**2016**	Collect seed and maintain collection sites
2012	Groom seed collection areas	**2017**	Collect seed and maintain collection sites
2013	Collect seed from collection areas	**2018**	Collect seed and maintain collection sites

Species for Conservation

A Forest Genetics program can also take a less intensive approach than seed orchards to 'tree improvement' and choose to emphasize conservation practices rather than selection and breeding. The Statewide Forest Plan, a 2004 Forest Service report on Wisconsin's Forests, and published research and forest health trends outline species at risk and point to a genetic need for conservation in the face of various threats such as new pests or climate change. The management practices emphasized here are drawn more from conservation biology than from plant breeding, but genetic concerns remain central.

One of the most immediate threats is related to the impacts on Wisconsin's forests from climate change. Although such change is uncertain in specific terms, a warming climate will have an impact on many species in Wisconsin that occur at the southern of their natural range (Mckinney et al. 2007) The impact of climate (and soils) on the distribution of major forest types in Wisconsin is well documented (Curtis, 1959) with many tree species reaching their northern or southern limits in Wisconsin. Even relatively small changes in temperature or precipitation (or both) could increase pest pressures on species with low stress tolerance (Millar et al. 2007.). The Forest Genetics program should be directly involved in interpreting anticipated climate change impacts on forests. As research on climate change impacts provides more definite results, we can provide sharper focus on species most at risk for extirpation.

In the meantime, the program will focus on tree species most at risk from current, relatively well-understood pressures. We identify a few of the most at risk species in Wisconsin and consider how we may best use our limited resources in collaboration with federal, regional and state partners.

Butternut

Threats

Butternut (*Juglans cinerea*), sometimes referred to as white walnut, is a native tree prized for its nuts by both wildlife and humans and for its quality lumber. The species is found throughout the state, with the exception of the northern-most counties, but has been declining steadily since the introduction of butternut canker disease (*Sirococcus clavigignenti-juglandacearum),* first reported in Wisconsin in 1967. The exact origin of the disease is unknown, but most agencies regard it as an 'exotic' pest. Trees infected with the fungus develop branch and stem cankers which eventually girdle and kill the tree. While tolerance or resistance to the disease has yet to be confirmed, putatively disease-free trees from infected areas have been screened (Ostry and Moore 2008). None have proven resistant although a few may have modest levels of tolerance to the fungus. A recent study has shown that there is a high level of genetic diversity within the species across its range (Ross-Davis, et al 2008). Given its environmental and economic history in Wisconsin and the continuing disease pressure, there is a need to conserve the species to help prevent its exterpitation from the state.

Present program

In 1995, the Forest Health Program of the Division of Forestry identified and provided scion wood to the USDA- Forest Service (St. Paul Lab) from 'superior' butternut collected in Wisconsin as well as potentially resistant material from disease-free trees from near Whitewater, WI. In addition to this effort, the Division, together with the Wisconsin Walnut Council and the HTRIC, has established a planting of grafted butternut selections in LaCrosse County that is being evaluated for possible resistance to the disease.

Available Plant Materials

Clone banks of putatively resistant selections have been made by the USDA- Forest Service. Wisconsin selections available to our program are currently located at their Northern Research Station (St. Paul, MN), Hardwood Tree Improvement and Regeneration Center (West Lafayette, IN) and Oconto River Seed Orchard (White Lake, WI).

Conservation Intensity

Cooperative interest for conservation of butternut resources is high, with our program sharing responsibility for maintenance and data collection for any tests that are established in Wisconsin. We should continue to identify and report trees which appear to be canker-free, especially those in stands with infected trees. Research on butternut canker continues in St. Paul by Forest Service scientists, so our costs in reporting such trees are minimal.

Future Program

The future of the butternut program involves working cooperatively with the USDA-Forest Service to facilitate the screening of grafted selections of putatively resistant materials and the establishment of field trials. Ultimately, tolerant or resistant material from these tests could be used to produce a clonal seed orchard to provide seed for the state nurseries.

Ash sp.

Threats

All species of ash in Wisconsin are under threat of infestation by emerald ash borer (*Agrilus planipennis* [Fairmaire]), an invasive species recently found in several counties in Wisconsin (2008). Mortality following infestation appears very high based on reports from Michigan and other nearby states, with no apparent genetic tolerance/resistance [G37] to this insect. Gene conservation and artificial regeneration are likely the only ways to preserve ash species on the landscape in the expectation that this insect will become naturalized in Wisconsin. However, our experience with emerald ash borer is too recent to gauge the rate at which ash populations will become infested, and we can only guess at the magnitude of potential losses.

Present program

We are currently drafting guidelines for seed collections of native ash species (white ash, green ash, black ash and blue ash, the latter restricted to the southern edge of the state) in concert with the USDA-Forest Service's National Seed Lab. Such germplasm collections will provide a reserve of genetic material for conservation as very few genetic studies or plantings of ash currently exist.

Available Plant Materials

Currently there are no available plant materials aside from natural stands. In the future, seed for genetic research could be available should the National Seed Lab acquire and store ash seed.

Conservation Intensity

We expect to make seed collections for approximately 300 families from natural stands widely distributed within the state. These collections will be preserved as seed in cold storage until control measures for emerald ash borer are developed.

Future Program

No selection or breeding activities are planned for any ash species. Our efforts will depend upon the success of various efforts to control or otherwise manage emerald ash borer.

Schedule

No schedule for seed collections has been established, but we are most likely to make such collections in years when large seed crops are available.

Eastern Hemlock

Threats

Eastern hemlock (*Tsuga canadensis*) represents a species that was once very abundant in northern forests until depleted by logging and fire during the early parts of the 20th century. Interest in hemlock continues to increase, especially as a 'conservation species' but state nurseries have not been able to secure enough seed to meet seedling demand . There is also a risk that despite increased regeneration of eastern hemlock the species could be vulnerable to the Hemlock Wooly Adelgid (*Adelges tsugae*), an exotic insect which is currently devastating hemlock populations in portions of the eastern US. Hemlock wooly adelgid has not been reported in Wisconsin.

Present program

No program currently exists for eastern hemlock conservation or improvement in Wisconsin, and only a very limited amount of past work on hemlock has been completed by scientists with the US Forest Service. Most past work has been ecological in nature, much of it centering on the historic role and value of hemlock in per-settlement forests. Hemlock is not uncommon in Wisconsin, and natural stands are available for seed collection or other conservation or genetics activities.

Available Plant Materials

No provenance tests or other range wide or regional collections of hemlock appear to exist in North America aside from very limited collections in various arboreta around the country.

Conservation Intensity

Conservation intensity activities for eastern hemlock would by low, and would consist primarily of identifying high quality stands for seed collection and preserving samples of collected seed from these stands. Development of seed collection areas may also be practical if planting demand warrants.

Future Program

Beyond monitoring hemlock for potential pest problems, and possibly creating one or more ‘seed production areas,’ no additional work is proposed for hemlock at this time.

Schedule

None established.

Appendix

Glossary

Seed zones
Seed zones are areas between which seed or seedling movement is restricted based upon expected loss of growth or adaptability due to environmental differences among geographic regions. Seed zones are common in the western US where movement among elevational zones is restricted. Seed zoning should be considered standard practice for all species in which progeny or provenance tests have demonstrated negative effects resulting from the indiscriminate movement of seed. In most instances, this serves a *status quo* function by ensuring that seed used for reforestation comes from populations well-adapted to the area. For many forest trees in the Lake States, 2-4 seed zones have been recognized, largely on the basis of climatic differences; adequate testing to verify these zones has been accomplished for some species such as white spruce, jack and red pine and black walnut (King and Nienstaedt, 1968; Nienstaedt and King, 1968; Wright et al., 1972; Jeffers and Jenson, 1980; Ager et al., 1982; Monk et al, 1998b). This testing is necessary because patterns of genetic variation do not necessarily correspond to patterns of environmental variation, and because the unique biology of each tree species may require the identification of unique seed zones.

Seed collection areas
Seed collection areas are stands of better-than-average quality from which seed can be collected at least once, e.g., seed collected at the time of timber harvest. Current collecting practices for several species in Wisconsin follow this approach, e.g., white ash, tamarack, sugar maple. Limited roguing of poor quality trees within the stand may be practice but any resulting genetic gain is likely due to provenance (seed source) and/or stand-to-stand differences rather than any selection.

Seed production areas
Seed production areas are stands of better-than-average quality that are managed for the production of improved seed. Management practices for these areas may include fertilization, protection and thinning to ensure the continued use of the stand for seed collection. Thinning eliminates poor quality trees in the stand (e.g., those with obvious defects such as forks and disease), thereby upgrading the genetic quality of seed produced while also stimulating flowering and seed production. Seed production areas can serve a valuable tree improvement function in the following ways:

1. as an interim source of seed while seed orchards are being developed, especially if early test results from open-pollinated progenies permit the identification of superior stands;
2. as a source of seed for minor species in which a seed orchard program is not justified;
3. as a source of potentially resistant seed from stands which have experienced heavy pest infestations. Levels of resistance in the decimated stands should be higher than in other stands, as the most susceptible trees have been eliminated.

Seed production areas differ from seed collection areas primarily in intensity of management for purposes of repeated seed collection. As with seed collection areas, the bulk of any genetic gain obtained is likely to come from seed source (stand-to-stand) variation.

Seed orchards
Seed orchards represent the most intensive level of tree improvement practical today. Seed orchards are assemblages of individuals (including clones) or families established and managed for the sole purpose of producing genetically improved seed. Two types of seed orchards are considered in this plan; seedling seed orchards and clonal seed orchards.

Seedling seed orchards are established using seedlings from open-pollinated seed collected from wild populations. The parent trees in the initial wild populations generally have not been intensively selected. Any expected genetic gain results from the selection and retention of the 'best' families within these seed orchards. Seedling seed orchards are relatively inexpensive to establish and are best suited for species which flower early when grown from seed, or for which more intensive 'plus tree' selection and clonal orchard establishment cannot be justified.

The major criticisms of seedling seed orchards are that in attempting to serve both progeny or family test and seed orchard functions, they are inefficient on both counts, and that selection within each seed orchard is too limited to achieve substantial genetic gains. However, from a pragmatic standpoint, tree improvement programs operating on a limited budget have frequently adopted the seedling seed orchard approach.

Second and later generation seedling seed orchards may be established using progenies from selected families in the first generation seed orchards. These second generation seedling seed orchards can be produced either by seed from controlled crosses, or open pollinated seed within the first generation orchard. In addition, the relatively low cost of seedling seed orchard establishment permits better use of resources for early selection and breeding to secure genetic gains via shorter breeding cycles. Our experience with jack pine (Edge, 1993) indicates that seedling seed orchards can be a successful and inexpensive tree improvement approach.

Clonal seed orchards are established using grafted scions (cuttings) from phenotypically superior trees selected from wild populations or plantations. They are generally accompanied by progeny test plantings designed to evaluate the genetic value of the select trees based upon the performance of their progeny. Genetic gains obtained from seed produced in such orchards are primarily due to the intensity of selection practiced. An additional increment of genetic gain can be obtained if such orchards are 'rogued' (or thinned) to eliminate the worst-performing families based upon progeny test results. Relative to seedling seed orchards, clonal orchards are considerably more expensive to establish because of the cost of initial selection, grafting, and management of the seed orchard in parallel with seed collection and progeny test establishment. For species which lend themselves to phenotypic selection, graft easily, and do not flower early when grown from seed, the clonal seed orchard may be especially useful. In addition, greater genetic gains can be achieved in the short-term using this approach.

Advanced-generation clonal seed orchards are generally established using scions of the most superior progeny produced by mating the original selections. At present, this approach is used only with white spruce and blister-rust-resistant white pine in Wisconsin.

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