Strategic Plan 2019-2029
Wisconsin Forest Genetics Program

White spruce seed orchard at Mead Wildlife Area November 2018

Wisconsin Department of Natural Resources
Division of Forestry
and
University of Wisconsin-Madison
Department of Forest and Wildlife Ecology

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Strategic Plan 2019-2029 Summary

Introduction

The WDNR has been involved in a Forest Genetics program since 1948 via longstanding partnerships with the University of Wisconsin-Madison (UW-Madison) and the USDA-Forest Service (USFS). The underlying principle for having a forest genetics program is to use the opportunity of artificial regeneration to plant trees and conserve genetic materials that are broad based and well adapted to Wisconsin conditions. It can also select and breed for increased productivity and tolerance to pests.

Goals and Scope of the Wisconsin Forest Genetics Program

The Forest Genetics 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 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.

Short-term, our efforts focus on using available information and resources to continue to improve the genetic quality of our present-day forest tree nursery stock. Long-term, our efforts involve maintaining a broad genetic base and biodiversity with principal reforestation species.

Resources Required to Achieve Program Goals

The WDNR provides personnel and funding for a 'tree improvement specialist' position at UW-Madison to perform the tasks for tree improvement activities. Equipment and infrastructure such as the tree nurseries, the greenhouse at the Forest Health Lab, and the land where the seed orchards and progeny test sites are located are all part of WDNR resources used to operate and manage the Forest Genetics Program. Moving forward, forest genetics activities, where practical, will be consolidated onto nursery properties to increase operational efficiency and effectiveness, and better management capabilities, such as irrigation or pest protection.

We currently manage 19 separate plantings totaling 132 acres. The species that are in the program are red pine (41 acres), eastern white pine (37 acres), jack pine (24.5 acres), white spruce (23 acres), and red oak, black walnut and butternut (6 acres combined). An additional 5 acres of butternut will be added this year as part of a new butternut canker trial.

The Reforestation Team partners with other tree improvement professionals and organizations for added resources to our program. These collaborations are with the USFS in a number of ways, technical committees such as the Northern Forest Genetics Association, and other state groups. We are also exploring other partnership opportunities, including potentially joining tree improvement and resistance breeding cooperatives, the Hardwood Tree Improvement and Regeneration Center, or other partnership opportunities to replace the expertise lost with the forest geneticist.

Program Emphases

A variety of factors influence the choice of species included in any forest genetics program. These factors include nursery stock demand for reforestation needs, historical and ecological factors, biological and genetic potential, and species threats. Red pine, white pine, jack pine and white spruce have dominated planting stock demand historically.

Eastern White Pine – This species will be an increasingly large component of future Wisconsin forests. White pine blister rust is the most serious disease, and we have collaborated with USFS research on this. We have two white pine provenance tests from 2002 and 2003 which will be the source of seed from a diverse genetic base well adapted to Wisconsin. The species has been **reduced** in emphasis as we no longer do research on southern Appalachian white pine.

Red Pine – This is an important timber species that will be an increasingly large component of future Wisconsin forests. There is comparatively little genetic variation in red pine, so controlled crosses for genetic gain are not done. The two remaining older orchards planted in 1970 will be harvested at some time when there is a good cone crop. A seed orchard was established in 2014 at the Hayward Nursery originating from the top families in our three original orchards. Red pine will be **maintained** in the program, with the new orchard providing seed of families from around the state well-adapted to Wisconsin.

Jack Pine – This species is quickly declining as a major component of state forests. Jack pine budworm and pine-oak gall rust are major causes of mortality for the species. Jack pine is characterized by large amounts of genetic variation, and opportunities for genetic improvement are excellent. Our program started research on jack pine with the establishment of the Hancock 1st generation 'index' population in 1980. We now manage four 2nd generation orchards that are producing cones we collect for the State Nursery, and two 3rd generation progeny tests that are future cone collection sites. Hopes are to gather the resources needed to produce a 4th generation planting and provide a future source of seed and establish genetic gains. Jack pine is being **advanced** in the program, with plans to make controlled crosses for a 4th generation progeny test.

White Spruce – This common forest species of northern Wisconsin is expected to maintain or modestly increase its volume in state forests over the next 20 years. There are three seed orchards developed from progeny tests of families from the Lake States region and Ottawa Valley, originating as seed from open-pollinated cones. We collect seed from these three orchards, but cone crops have been very sparse in recent years. We have a beginning grafted orchard at the Hayward Nursery, and we plan to expand this through grafting with scionwood from the three older orchards. White spruce will be **maintained** in the program.

Black Walnut – Sawlogs of black walnut are among the most valuable of Wisconsin species, though it only grows in the southern part of the state. Thousand Cankers Disease is a potential serious threat if it spreads to Wisconsin. There is one grafted orchard being managed that has begun providing seed from trees of select origins. Black walnut will be **maintained** in the program.

Butternut – The species is found in most of Wisconsin, but has been declining steadily since butternut canker disease was first reported in the state in 1967. Native butternut easily hybridizes with at least two exotic species, and these hybrids are typically more resistant to the canker disease than the native species. The Reforestation Team is embarking on an expanded collaboration with the USFS to replace a smaller planting with a 5-acre trial at Bell Center to determine if any resistance to the butternut canker disease can be found in strictly native types. We also manage a 1-acre grafted orchard at the Hayward Nursery of some putatively resistant material. Butternut will be **maintained** in the program.

Red Oak – There is one orchard of over 200 grafted red oak in the program at the Bell Center Orchard. Red oak will be **maintained** in the program as a future seed production area.

New Initiatives

The following are some areas of tree improvement that may be explored in the coming years.

Assisted Migration

This strategy involves the human-assisted movement of species to suitable habitats in response to climate change. Three levels of assisted migration are:

- Assisted Population Migration – moving individual genotypes with a species' native range
- Assisted Range Expansion – moving a species to areas just outside of their native range, mimicking natural range expansion
- Assisted Long-Distance Migration – moving species to areas far outside their native range

Insect and Disease Resistance Breeding

Forests are under attack by invasive insects and diseases to which the host populations have low levels of resistance. Due to the critical need for genetic resistance programs to combat these attacks, an Eastern States' Coalition for Forest Tree Breeding is being proposed to provide a framework for states to collaborate by sharing costs, increasing efficiency, and establishing continuity.

Seed Production Areas (SPAs)

Seed production areas are natural stands or plantations managed for seed collection purposes of known origin and phenotype. The focus is on species adaptability and cost effectiveness of collection, not genetic gain.

Silviculture and Genetic Field Trials

Wisconsin Forest Genetics supports silviculture trials, particularly trials utilizing and testing new species and genotypes, including bottomland and swamp hardwood restoration planting, and climate adaptation trials.

Urban Planting Stock

A majority of landscape-sized trees planted in Wisconsin's urban/community landscapes are comprised of only five tree genera. Low species variety is due to the limited supply offered by private nurseries. Proposed initiatives include nursery trials to determine the viability of propagation and production of species of interest to forestry professionals, and using nursery facilities to experiment with tree species' ability to adapt to an urban condition.

White Oak Cooperative

Oak regeneration is predicted to be insufficient to meet future market demands, especially for the bourbon barrel industry. Wisconsin DNR is considering increasing the number of white oak seed orchards as a source of seed for well-adapted oak seedling of known genetic origins and quality.

Eastern White Pine Specific Gravity

The specific gravity of white pine is inadequate for its use in cross-laminated timber. If work to identify or breed for higher density in white pine were done, it could potentially raise the value of white pine timber significantly for the fastest increasing tree species in Wisconsin.

Strategic Plan 2019-2029 Full Report

Introduction

Justification for a Forest Genetics Program in Wisconsin

Forest management systems which use artificial regeneration as a tool rely on genetic materials to propagate by seed or cutting the various species being regenerated. It is an opportunity to introduce seed/seedlings whose genetic constitutions are new or different from what existed previously. If the genetic composition of these propagules is 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' (WDNR) Reforestation Team, which ensures that the seed used for direct seeding or growing forest nursery stock is biologically sound. It also ensures that the seed supply represents a broad genetic base that is well-adapted to the climatic, ecological, and edaphic conditions of the reforested site, and that it 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 via longstanding partnerships with the University of Wisconsin-Madison and the USDA-Forest Service (USFS). In 1983, a Strategic Plan for Wisconsin's Forests[1] 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 sate nursery program.

The 2004 Statewide Forest Plan[2] identified multiple objectives on the theme of sustainable forestry. Objective 30 of that 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. Other plan objectives call for the conservation of native tree species and biodiversity, which relates directly to the genetic conservation aspects of the Forest Genetics Program. An additional objective 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, tree improvement is relevant in providing propagules that yield a more productive forest with trees of better form and growth and better tolerance of pests than those of the previous rotation.

In 2012, the WDNR Division of Forestry (Division) created a Strategic Direction (SD) plan intended "…to describe the Division of Forestry's niche within the broader forestry community in addressing major issues and priority topics and our clear intent for how we intend to achieve those objectives in the next five years". One element of the SD concerned reforestation and noted that "…regeneration is critical to sustainably managing Wisconsin forests…. Encouraging landowners to regenerate forests will add to Wisconsin's ability to sustainably manage its forests." The plan further noted that "…tree improvement and forest genetics work is important in helping to ensure healthy, sustainable forests." In 2017, an updated plan continued the action and initiatives put forth in the 2012 document, though the forest geneticist position was eliminated. The plan indicated the Division "…will maintain existing contracts, explore new contracting opportunities, and continue to utilize existing staff within the Reforestation Team to accomplish tree improvement needs."

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 2029. The plan considers a schedule of activities for achieving short- and long-term objectives while providing 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 program's 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 Forest Genetics 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. Forest genetics programs are constructed in such a 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 broad directions 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 health 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 their 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.

The second goal is directly related to the Department's mission of preserving biodiversity, especially at the genetic level given the 2004 Statewide Forest Plan objective to "Conserve, protect, and manage for biological diversity and support continuing research on biological and ecosystem diversity. In addition, the 2017-22 Division SD stated that "The capacity of Wisconsin's forests to continue to support existing and emerging industries and produce beneficial environmental services, clean air and water, wildlife habitat, and soil conservation, is contingent on Wisconsin's forests being protected from damaging agents and sustainably managed." Both goals are integral parts of a long-term tree improvement program.

In the short-term our efforts focus 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 with principal reforestation species 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 stressors.

Duration of Present Plan

Tree breeding activities are necessarily long-term, in part because of their longevity and the long age to sexual maturity for many tree species, but also because of the open-ended opportunities for obtaining incremental improvement in successive generations through selection and breeding efforts. However, for planning purposes some finite time frame is required. This plan outlines directions for tree improvement activities in Wisconsin for the next ten years through the year 2029. Considerable latitude will be required for annual work planning, both in scheduling short-term activities due to biological constraints, and in accommodating 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 providing/producing improved seed. At the least intensive end of this spectrum, we only control the geographic limits of seed/propagule movement. At the most intensive end, trees are selected and bred to produce progeny with specific traits favored by the managers. Certain approaches such as seed orchards can be further divided based on 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 strategic plan, new genetic technologies have become more widespread – 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. The development of putatively tolerant/resistant poplars (to leaf rusts) and American chestnuts (to chestnut blight) demonstrate that such approaches can have value under very specific conditions. Currently, the WDNR uses only native species propagated by seed in its reforestation operations. Our forest genetics program lacks the resources needed to pursue the complex and expensive approaches favored by some enterprises. The production of GMOs will not be considered in this plan.

Resources Required to Achieve Program Goals

Personnel

WDNR Reforestation Program and Division personnel have played important roles in the establishment and management of tree improvement plantings. The technical and professional assistance for tree improvement activities provided by UW-Madison faculty and staff has been equally important, and this cooperation is expected to continue. The responsibilities of the former WDNR forest geneticist position have been divided and included in the position descriptions of the reforestation team leader, regeneration specialist, and the UW-Madison tree improvement specialist. In the future, data analysis and activities related to tree improvement will be accomplished utilizing our partners within the USFS, the Hardwood Tree Improvement and Regeneration Center (HTIRC) at Purdue University, and other Division staff. The Reforestation program is also exploring additional partnership opportunities with existing and potential tree improvement cooperatives.

Cooperative efforts between the Division and UW-Madison, Department of Forest and Wildlife Ecology, led to the establishment of a joint 'tree improvement specialist' position currently funded by the WDNR on an annual basis. The university continues to employ faculty whose responsibilities include cooperation with state and federal agencies in forestry research and development, including tree improvement. In addition, limited-term employees (LTE's) are utilized on an as-needed basis to accomplish specific time-dependent tree improvement program activities. These arrangements are expected to continue. However, if partnerships and/or personnel conditions change, the Division may re-evaluate existing staffing levels and adjust them to fit program needs.

Budgets

Current budgets for the Reforestation Team are adequate to carry out this plan as proposed and include funding for tree improvement and support for one joint specialist position in tree improvement split between the UW-Madison (10%) and the WDNR (90%). Funding up to $80,000 has been directed from the Forest Geneticist position and is available to tree improvement and resistance breeding cooperatives, the HTIRC, or other partnership opportunities to replace the forest geneticist duties.

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

Nurseries

The Division operates three forest tree nurseries located at Boscobel, Wisconsin Rapids, and Hayward, Wisconsin. As seedling sales declined, production operations were consolidated to the Wilson State Nursery in Boscobel, with seedling production ceasing at the Hayward Nursery in 2012 and the Griffith Nursery in 2017. These properties have been re-purposed for other uses complimentary to the Reforestation program, including forest genetics activities. Consolidation to Wilson Nursery provides adequate capacity to accommodate the production and distribution of up to eight million seedlings annually. Current nursery distribution has declined to about 3-5 million seedlings annually over the past 5 years. However, current stock projections suggest an increase in demand to 4-6 million seedlings over the next 5 years. Production fluctuates with the availability of federal cost-sharing funds and the existence of other reforestation incentives. At some point, demand for tree seedlings could increase to accommodate public and private sector planting needs. How new initiatives outlined in this plan may be implemented may also have an impact on future nursery demand.

Greenhouse

The updated greenhouse complex facility, part of the DNR Forest Health Lab at the Nevin Fish Hatchery in Fitchburg, continues to be available for use by the Reforestation program. This partnership with Forest Health works well and is expected to continue.

Equipment

Heavy equipment for site preparation, planting, thinning, and maintenance is typically available through our WDNR partners to meet the needs of the program. Cooperation among the state nurseries, other WDNR programs, and UW-Madison has been very good in terms of utilizing personnel and equipment for maintaining existing tree improvement plantings. Some special equipment, especially for cone collection and breeding, has been rented on an as-needed basis. These arrangements are expected to continue.

Tree Improvement Species and Genetics Testing Sites

The Tree Improvement Program currently manages 19 plantings on 132 total acres of native tree seed orchards and progeny tests located on State of Wisconsin land. There are four conifer species: jack pine (*Pinus banksiana*), red pine (*Pinus resinosa*), Eastern white pine (*Pinus strobus*), and white spruce (*Picea glauca*). Additionally, there are three selected native hardwood plantings: a grafted black walnut (*Juglans nigra*) and northern red oak (*Quercus rubra*) orchard, a young grafted butternut (*Juglans cinerea*) orchard, and a butternut seedling trial testing for butternut canker (*Ophiognomonia clavigignenti-juglandacearum*) in native butternut trees. These sites are distributed across the state and present a significant logistical challenge for the performance of maintenance tasks, cone collection, and breeding activities. It is very desirable to locate future seed orchards and breeding populations in or near established DNR facilities within the species’ natural range for protection, maintenance and efficiency of management.

The following list enumerates by species the current array of tree improvement plantings by county of location, year established, and acreage for each site.

<u>Red Pine</u> (41 total acres)

Lake Tomahawk (Oneida County) – 1970 on 15 acres
Ten Mile Creek (Wood County) – 1970 on 15 acres
Hayward Nursery (Sawyer County) – 2014 on 11 acres

<u>Eastern White Pine</u> (37 total acres)

Sawyer Creek (Washburn County) – 1983 on 12 acres
Lake Tomahawk (Oneida County) – 2002 on 15 acres
Black River Falls (Jackson County) – 2003 on 10 acres

<u>Jack Pine</u> (24.5 total acres)

Ten Mile Creek II (Wood County) – 1996 on 6 acres
Greenwood (Waushara County) – 1997 on 5 acres
Hauer Springs (Sawyer County) – 1999 on 6 acres
Ten Mile Creek III (Wood County) – 1999 on 1 acre
Black River Falls (Jackson County) – 2011 on 5 acres
Hayward Nursery (Sawyer County) – 2014 on 2 acres

<u>White Spruce</u> (23 total acres)

Lake Tomahawk (Oneida County) – 1969 on 6 acres
Mead Wildlife Area (Marathon County) – 1982 on 6 acres
Sawyer Creek (Washburn County) – 1989 on 10 acres
Hayward Nursery (Sawyer County) – 2015 on 1 acre

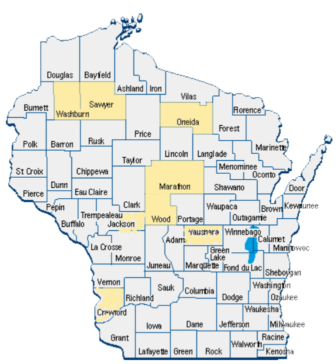
<u>Black Walnut and Northern Red Oak</u> (4 total acres)

Bell Center (Crawford County) – 2004 through 2015 on 4 acres

<u>Butternut</u> (2 total acres)

Bell Center (Crawford County) – 2010 on 1 acre
Hayward Nursery (Sawyer County) 2013 on 1 acre

19 seed orchards and progeny tests planted on 132 total acres.



Wisconsin Counties highlighted which host one or more tree improvement plantings

Partners

Numerous individuals and agencies, both within and outside the Wisconsin DNR, assist with various aspects of the tree improvement program. In addition to nursery personnel, staff from the Division's Forest Health Program have been especially prominent in supporting tree improvement efforts. Other technical assistance from outside sources includes:

- USFS, Region 9, National Forest System. The Oconto River Seed Orchard has provided the state with plant materials, including white spruce and white pine, and assistance with tree improvement activities such as grafting, orchard management, and white pine blister rust breeding efforts.
- USFS Hardwood Tree Improvement and Regeneration Center (HTIRC) at Purdue University, West Lafayette, Indiana. Researchers here are collaborating with Wisconsin TIP on a 5-acre butternut canker trial and have provided other butternut materials
- USFS, State and Private Forestry. Carrie Pike, Northeast Regeneration Specialist in West Lafayette, IN, has been a source of technical expertise and networking with other tree improvement experts in the region.
- USFS, Reforestation, Nurseries, and Genetics Resources (RNGR). A source of current technical information for people who grow forest and conservation seedlings, and links to other tree improvement and conservation professionals.
- USFS, Northern Forest Experiment Station. Geneticists and other staff at the Forest Sciences Lab, Rhinelander, Wisconsin, have provided both technical assistance and plant resources in the past. Changes in staff due to relocation or retirement have lessened this relationship presently.
- Technical Committees. Members of the Northern Forest Genetics Association provide valuable technical and educational assistance to tree improvement programs throughout the region.
- University of Minnesota, Cloquet Forestry Center, Cloquet, Minnesota. Researchers with the Minnesota Tree Improvement Cooperative have collaborated on specific projects in the past.
- Other cooperators. Other state forestry programs or cooperatives in the North Central Region.

In addition to these current relationships, the Reforestation program is exploring partnership opportunities which could expand the range of resources and expertise currently available to us. Existing or proposed cooperatives, such as the Minnesota Tree Improvement Cooperative or the Eastern States Coalition for Forest Tree Breeding, are being evaluated for benefits and costs to join. We are also looking at the possibility of the creation of a regional tree improvement cooperative between us and other states in the region.

Program Emphases

A variety of factors influence the choice of species included in any forest genetics program. In Wisconsin, these relate to the goals of the Division regarding reforestation activities, as well as the genetic endowments of individual species.

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 volume of planting stock needed and help determine the direction and intensity of tree improvement activities.

Past demand for planting stock provides one basis for establishing reforestation demand, and good information on previous nursery stock production is available for Wisconsin. However, future demands may vary from past years 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 3 and 5 million trees per year (**Figure 1**). Two-thirds of nursery production is distributed to private non-industrial forest landowners, with the remainder divided between county, state, and industrial users. In recent years, several forest products industries, especially paper companies, have reduced their planting activities as industrial timber lands have been sold to other groups of investors. County forests, private landowners, and forest products industries are also increasingly buying planting stock in containers as opposed to bareroot stock, which also has negatively impacted state nursery sales.

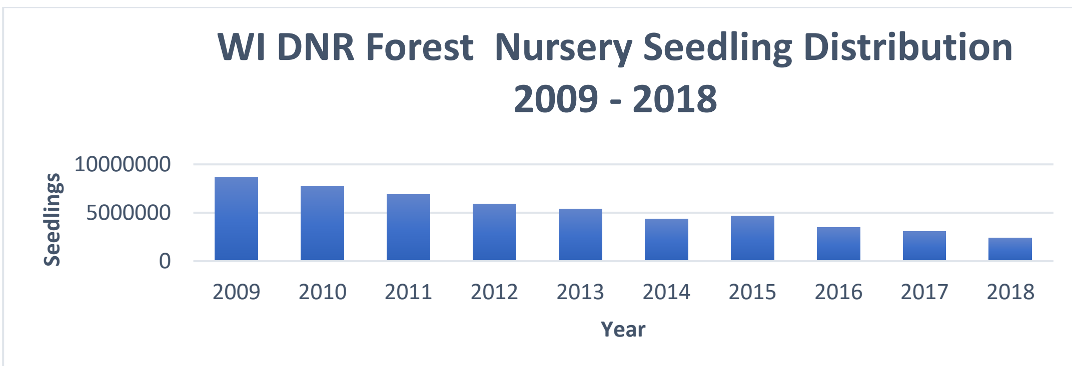


Figure 1. Seedling distribution summary for Wisconsin state forest nurseries, 2009-2018.

Red pine, white pine, jack pine and white spruce have dominated planting stock demand during the recent past (**Figure 2**). Collectively, they represent 80% or more of distributed seedlings during the past few decades. Reforestation trends point to a steady to slightly upward increase in seedling demand for the four major conifer species, despite increased reliance on natural regeneration for some species and a reduction, particularly by forest industry, in the acreage dedicated to red pine plantations. Red pine may experience a resurgence, provided that when the large swaths of stands established during the CCC and Soil Bank eras reach maturity and are replaced. However, this will depend on the landowners and managers desire to re-establish the species. 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.

Current nursery stock demand projections suggest a stable to slight upward trend to 4-6 million trees in the next five years. These demand projections, produced in a joint effort by the Reforestation team and other WDNR, county, and federal forestry staff, 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 the drastic fluctuations in commodity prices and the rise of central pivot irrigation equipment on historically forested landscapes.

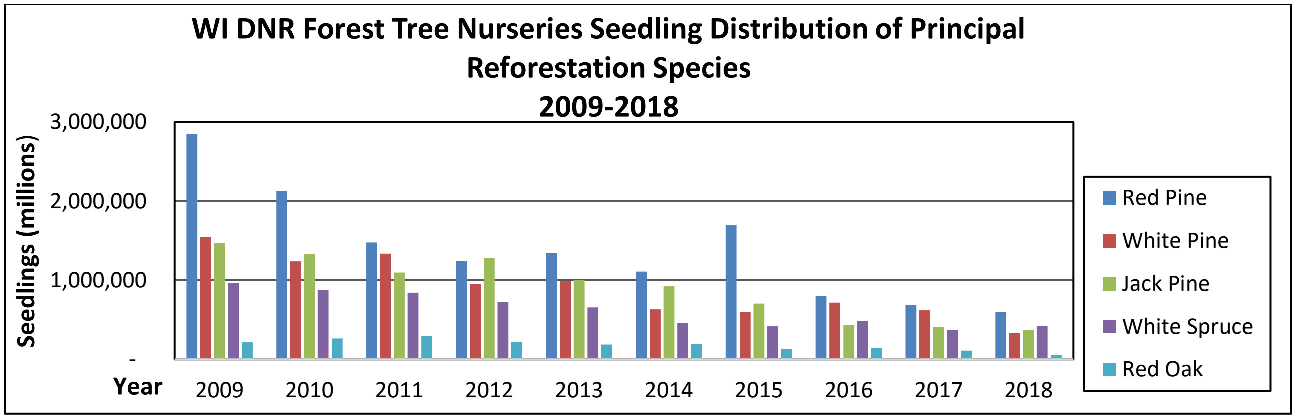


Figure 2. Seedling production of principal reforestation species from Wisconsin state nurseries 2009-2018

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.[3] 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 must be conducted simultaneously. However, given the reality 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.

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 improvement within a species. In addition, the value of genetically improved trees to forestry activities in Wisconsin, the anticipated levels of improvement 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 planting stock for reforestation provide a reasonable basis for determining species emphases for tree improvement efforts in Wisconsin.

Species Threats

From the perspective of conserving forest genetic resources, threats to certain tree species should be evaluated in terms of any need for assisted conservation. Global trade has facilitated the spread of exotic pests that damage trees and increased their rate of spread throughout North America. "Old" pests 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*), 1000 Cankers Disease of black walnut (combined activity of the *Geosmithia morbida* fungus and *Pityophthorus juglandis*, the walnut twig beetle), Beech bark disease (combined interaction between a Beech scale and a *Neonectria* fungus) 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 pest introductions, and biological factors influencing the extent and patterning of genetic diversity are all factors that influence our ranking of species for conservation.

Species Currently Emphasized for Improvement

Eastern White Pine

Status in Wisconsin Forests

White pine is one of the largest and longest-lived tree species in Wisconsin. It is mostly found in the northern and central portions of the state growing on a wide variety of habitat types. It is common in pine forest types as well as mixed with hardwoods in oak-hickory, oak-pine, aspen-birch and maple-basswood forest types.

The growing stock volume of white pine has tripled since 1983 and has increased by 43% since 2004 to 8% of total statewide volume.[4] This report also shows the number of sawtimber and pole-size white pine trees increasing by over 60%, while sapling-size trees increased over 120%, between 1996 and 2015. These figures show that white pine will be an increasingly large component of future Wisconsin forests, with the growing stock volume continuing to rise for the next 40 years.

The most serious disease of Eastern white pine is white pine blister rust (*Cronartium ribicola*). The fungus infects the pine needles when moisture is present, then moves into the branches, where cankers are formed. The cankers eventually girdle the branches and main stem, stressing or killing the trees. The fungus needs to infect both white pine and a *Ribes spp.* to complete its life cycle, so white pine is most at risk for this disease if gooseberry or currant plants are present in the surrounding vegetation

Potential

Eastern white pine remains one of the most common trees grown in the state nurseries today, with an annual production of approximately 750,000 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. 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*).

History of the Program

White pine has previously been studied in Wisconsin for performance of seedlings sourced from the southern Appalachian region because of their potential for increased growth. As a general rule, seed from stands in the southern Appalachians is recommended for planting in most of the eastern U. S.[5] Survival and growth were examined at six Wisconsin locations beginning in 1986. Results from a Wisconsin trial indicate that eastern white pine from southern Appalachian seed sources will survive in Wisconsin, but above average growth is only evident in southwest Wisconsin. Seed sources from the southern Appalachians are no better than, and usually worse than, nursery stock of local seed sources. Trees sourced from the southern Appalachian seed sources experienced severe ‘needle burn’ of the foliage during most winters.[6] The study recommended that southern seed sources not be planted north of a line between Eau Claire-Wisconsin Rapids-Sheboygan and concludes that seedlings from southern Appalachian seed have little value in Wisconsin at present. The six trial sites are no longer being managed.

The Sawyer Creek white pine, planted in 1983, are grafted trees from a USFS blister rust program, and originate from families deemed of high blister rust resistant potential based on their tests from that time. This trial was planted at orchard spacing and has been maintained and used as a source of seed for the nursery system in the past. There is no reliable data to support the resistance of these families, and seed from these trees cannot have claims of improved resistance. The USFS Oconto River Seed Orchard, where the scions used for grafting the Sawyer Creek orchard came from, continues its program testing for blister rust resistant families. Potential future efforts in Wisconsin Tree Improvement to discover resistant genotypes would likely be in the form of trialing material from the Oconto River program as a form of cooperation to identify the potential for capturing blister rust resistant genetics.

Present Program

Beginning in 1983, through a cooperative effort with the USFS at Oconto River Seed Orchard, grafts of putative blister rust-resistant eastern white pine were obtained and planted within a 10-acre clonal seed orchard at the Sawyer Creek Fishery Area (Washburn County). Seed has been collected from this orchard since 1990 for use by the state nurseries, 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 the material. One clone was eliminated from the seed orchard based on seedling performance in this test. The blister rust-resistant selections at Sawyer Creek were not made with regard to growth rate or other traits.

To examine the potential of eastern white pine with respect to other traits of interest, a study was initiated to examine the extent and patterning of genetic variation in eastern white pine. In 2002-03 provenance/family test was established using progeny of 256 eastern white pine families from Wisconsin, Minnesota and the Upper Peninsula of Michigan near Lake Tomahawk (Oneida County). A companion test using a subset of 248 of these families was established in the Black River State Forest in 2003. The progeny tests were measured in 2011 and 2012 and have been thinned to allow the trees with the best growth and form better tree spacing. Lake Tomahawk has been thinned to 28% of the original test, and Black River Falls been thinned to about 50%, with another half of the remaining trees marked and waiting for removal. 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 benefit will be the development of two seedling seed orchards for future seed production and genetic resource conservation of Lake States white pine.

Available Plant Resources

With the exception of materials controlled by the USFS at their Oconto River Seed Orchard, white pine materials of known genetic origin are almost non-existent in Wisconsin. The only provenance test, a small 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, our 2002-2003 tests of 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. Our current tests address this need.

Another perceived problem with white pine reforestation is white pine weevil (*Pissodes strobe*), but research 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. 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. The younger plantings at Lake Tomahawk and Black River Falls could potentially start producing cones in the next 5 years, providing seed sources of locally adapted white pine with a genetically diverse background from selected mother trees. The white pine at Sawyer Creek continue to produce cones.

Future Program

The eastern white pine program is being **reduced** in the Strategic Plan for 2019-2029. Because southern Appalachian white pine has not been shown to provide increased productivity in any but the most southwestern portions of Wisconsin, research and management are no longer being performed for plantings of these origins.

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 the Black River State Forest, especially for growth related traits; and (2) continued cooperation with the USFS blister rust screening program at Oconto River Seed Orchard. Both activities will provide sources of genetic materials and seed for future nursery needs, but neither will contribute large quantities of seed in the near term.

Red Pine

Status in Wisconsin's Forests

Red pine is one of Wisconsin's most important timber species. It commonly is found in the northern and central portions of the state growing on dry to dry-mesic sites in pine forest types as well as mixed with hardwoods in oak-pine and aspen-birch forest types. The majority of Wisconsin's red pine (78%) was planted.

The growing stock volume of red pine has doubled since 1983 and has increased by 69% since 1996 to 7.9% of total statewide volume.[4] This report also notes the volume of sawtimber red pine has doubled since 1996 while seedling and sapling-size trees have declined between 1996 and 2015. It appears that red pine will be an increasingly large component of future Wisconsin forests, with the growing stock volume continuing to rise in the near future. However, the lack of regeneration (both natural and planted) suggests that at some point, depending on harvest levels, red pine will decline as a proportion of Wisconsin's forest growing stock.

The most serious disease of red pine is Annosum root rot incited by *Heterobasidium irregulare*. This fungus infects the stumps of freshly cut trees and moves into the roots, where it can then infect living trees via root grafts. The fungus eventually girdles the cambium, stressing or killing the trees.

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. As recently as 1989, Wisconsin sold more than 15,000,000 red pine seedlings from the state nurseries. The state forest nurseries in Wisconsin currently produce 800,000 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. Results from 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.[7] Tree improvement and breeding efforts with red pine are somewhat controversial because of the obvious restriction of potential genetic gain.

History of the Program

The once extensive red pine reforestation program in Wisconsin, and the large demand for seed, led to the development of a red pine tree improvement program beginning in 1965. The basic justification for this program is that even small genetic gains, when applied through large reforestation programs, could have substantial cumulative benefits.[8] Utilizing open-pollinated seed collected from 310 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). The seed orchards were established at a north, central, and southern location to provide seed for the 3 state forest nurseries should subdivision of the state into separate breeding zones be required. Current information indicates that this is not necessary, and that Wisconsin can be considered one breeding zone or seed zone for red pine.[9] A limited amount of seed has been collected from the Avoca, Lake Tomahawk and Ten Mile Creek seed orchards during the past decade, and the Avoca orchard was eliminated following a period of drought and decline. The Lake Tomahawk and Ten Mile Creek seed orchards remain but have produced little seed.

Present Program

Current information indicates that Wisconsin can be considered one breeding zone or seed zone for red pine.[9] Seed from future seed crops could be used for statewide distribution with little risk of growth loss or adaptability concerns. Following several thinnings, the remaining seed orchards now retain the "best" individuals of the "best" families based upon height and volume estimates. Selected individuals from within 125 families 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 was collected from almost all selected trees and was used to create a new seed orchard at the Hayward nursery.

Available Red Pine Resources

The DNR seed orchards currently contain families originating from throughout Wisconsin. In addition to the materials included in the 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,[10] 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 impractical.[9] Also, in screening trials for disease resistance to *Scleroderis* canker, red pine progenies appear uniformly susceptible.[11] 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.[12] In addition, pesticide applications are invaluable in protecting cone crops from flower initiation to cone harvest.[13]

Spacing has a large effect on flower and cone production, with wider spacing yielding larger crops.[14] Assuming an average seed yield of 25 seed per cone, 52,000 seed per lb., 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 with 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. At the present time the state forest nurseries sow about 33 lbs. of red pine seed per million seedlings produced. This equates to an annual need for 25 pounds of red pine seed for the state nursery.

Future Program

The red pine program is being **maintained** in the Strategic Plan for 2019-2029 at current levels of improvement and conservation. The Hayward red pine will conserve the genotypes originally collected in the 1960s throughout its Wisconsin range, and provide a reliable seed collection area at a well-maintained site.

Controlled crosses will not be made in our red pine. Low genetic variation[15] compared to other pine species makes red pine impractical for genetic improvement work given the expectation of limited genetic gain. While red pine is no longer a strong candidate for tree improvement, the conservation and future use of the red pine genetic resource is still important. These provenance trials contain red pine from around Wisconsin and suggest that red pine is well adapted to the growing conditions here.

Jack Pine

Status in Wisconsin Forests

Jack pine typically occurs on the well-drained sandy and outwash soils of northwest and central Wisconsin, but it also is found to a lesser extent in the northeastern part of the state. It is a common component of Kotar's Region 1, 2, 5 and 9 Habitat Types[16] and is typically found on pine types or mixed with oak and/or aspen. It has been a valuable timber and pulp species and an important component of Wisconsin's northern forests. Jack pine acts as a 'pioneer species' in early successional stages of natural regeneration, particularly when the cones of serotinous trees open and release their seeds following a fire or very hot summer days. Jack pine stands also provide critical wildlife habitat, notably for the federally endangered Kirtland's warbler in young pine barrens. Many other species depend upon jack pine for winter cover and the seed from persistent cones as a food source.

Jack pine is quickly declining as a major component of the state's forests. The volume of jack pine in the state is predicted to decrease by 2/3 in the next 40 years.[4] Over twice as much volume each year is harvested as is being replaced by new growth. In addition, the ratio of mortality to standing volume is 3.2%, almost three times higher than the statewide average for all species. A major cause of this high mortality is repeated defoliation by jack pine budworm (*Choristoneura pinus*).

Potential

Jack pine is one of the most widely distributed conifers in Wisconsin. Historically, regeneration was exclusively by natural regeneration or by direct seeding. Recently, the establishment of jack pine plantations has increased, in part due to conservation programs, with state nursery production in Wisconsin currently about 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. The loss of important wildlife habitat is as important as the loss of timber volume.

Jack pine is characterized by large amounts of genetic variation for many traits of interest including growth rate, stem form and wood specific gravity.[17] Opportunities for genetic improvement in these traits are excellent 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).*

History of the Program

In 1980, as a part of a regional jack pine testing and breeding program, the University of Wisconsin-Madison established four 'index' populations in 1980 at the Hancock Research Station (Waushara County) to provide a research framework for genetic studies.[18] Each population contained twenty unique families from Wisconsin, Michigan or Minnesota. Research with these populations confirmed the high levels of genetic variation noted in earlier provenance tests. Estimates of genetic gain in jack pine for growth rate ranged from 11-15%.[19] As part of this program the WDNR established two 'breeding' populations, replicates of the 'index populations but using different families, one at Bean Brook (Washburn County) and one at Ten Mile Creek (Wood County) to take advantage of information learned from the 'index' populations.

Following selection of the best individuals from all families to serve as parents, a second generation set of 'index' populations was bred and established at the Ten Mile complex (Ten Mile II). An additional breeding population (Ten Mile III) was created using controlled crosses using parents drawn from families at Ten Mile I and out planted at the Ten Mile Creek Seed Orchard Complex in 1999. The original breeding population there (Ten Mile I) was removed in 2004 due to declining stand health.

Second generation populations were created by selecting mother trees with suitable phenotypic traits in the first-generation populations and pollinating their flowers with pollen from other select trees within that same orchard. The resultant progeny were planted at/near Ladysmith, Hauer Springs (Sawyer County), and Ten Mile II (Wood County) to provide opportunities for further evaluation and selection, and eventually as a source of genetically improved seed.

Two 3rd generation progeny tests/breeding populations have been created using polycross pollinations from the Ten Mile breeding populations. The jack pine at Black River Falls were planted in 2011 and originate from Ten Mile II crosses. Data was collected here for height, form, and oak-pine gall rust in 2016, and this was used to generate a thinning map. 50% of the trees were rogued out in late 2018 to allow more optimal spacing. Trees here have been producing cones the past two years. The orchard located at Hayward was planted in 2014 and originates from Ten Mile III crosses. These trees were scored for height, form, and gall rust in 2018.

Present Program

Current seed collection activities occur in the second-generation orchards at Ten Mile, Greenwood, and Hauer Springs. Estimates of expected genetic gain in height growth rate range between 11-15%.[19] Selection of trees for future breeding within these seed orchards has emphasized volume growth, resistance to pine-oak gall rust and crown characteristics.

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 crosses between select 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.

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 USFS are located in 9 different counties. Numerous family tests established by the USFS 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. 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. It is estimated that seedling seed orchard production could average 108,000 seed/acre/year by age 6,[20] and by age 8, yields were projected to increase to 655,000 seed/acre/year.[21] 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.[22] As there are approximately 120,000 seed per pound,[19] 8 acres of seed orchard (by age 8) would satisfy annual nursery needs.

Future Program

The jack pine program is being **advanced** in the Strategic Plan for 2019-2029. Goals include creating a 4th generation progeny test and seed orchard, comparing trees from woods-run versus program progeny to validate expected gains in production, and conservation of diverse genotypes from the Upper Great Lakes States.

The third-generation seed progeny tests at Black River Falls (Jackson County) and Hayward (Sawyer

County) will be eventually rogued to seed orchard spacing. Along with the second-generation orchards at Ten Mile (Wood County), Greenwood (Waushara County), and Hauer Springs (Sawyer County), these newer plantings will provide sufficient seed to meet WDNR requirements for jack pine.

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 ensure our ability to regenerate jack pine on the landscape in the future.

Breeding fourth-generation progeny tests with controlled crosses between selected material from previous generations is important to continue the genetic gains achieved in previous generations. New plantings are best placed where deer browsing can be controlled, and irrigation and regular maintenance provided, so the data for performance is not compromised. The nurseries would be ideal sites for those requirements. Seedlings from wild-collected seed will be included in a new planting to compare with seedlings from breeding selections to affirm expected gains in growth.

White Spruce

Status in Wisconsin Forests

White spruce is a common forest tree in the northern one-third of Wisconsin, principally occurring in Kotar's Habitat Type Regions 2, 3 and 4.[19] It occurs on mesic and wet-mesic sites mixed with hardwoods in aspen-birch forest types, and with balsam fir forest types, growing best on podzolized loams and clays and faring poorly on sands. The volume of spruce of all sizes has increased significantly, up 41% since 1983 and 15% since 1996.[4] Even though the mortality rate is higher than the statewide average for all species, white spruce is expected to increase in volume through 2035. It is not an important timber species, accounting for only 1% of roundwood product, and being just slightly below average density for softwoods.

The growing stock volume of white spruce represents about 2% of total statewide volume,[4] an increase of some 15% since 1996. Numbers of stems have increased in all size classes since 1996, probably a result of limited harvesting and the ability of spruce to tolerate shaded growing conditions. Roundwood harvests of white spruce represent about 1% of statewide totals, but pulpwood harvests of white spruce have declined 40% since 2005. White spruce will remain a modest component of Wisconsin's northern forests, with the growing stock volume continuing to rise for the foreseeable future.

Potential

Approximately 400,000 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.[23] 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.

History of the Program

A cooperative agreement between the Wisconsin DNR and the USFS 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.[24]

A 6-acre seedling seed orchard comprised of 175 families representing materials from Ottawa Valley, Ontario, and selections from the Lake States region made by the USFS, 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.

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.

Present Program

Current efforts are limited to management of the existing seed orchards, together with limited grafting of scions from superior trees identified within the plantings at Lake Tomahawk and the Mead Wildlife Area for incorporation into the small seed orchard just beginning at Hayward.

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 in the future. 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. Spruce budworm defoliation occurs at low levels in some Wisconsin forests but is not considered a serious pest.

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. Estimates of cone and seed yield from grafted white spruce seed orchards following a good flowering year were made 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.[25]
In 2017, cones and their seed were collected at the Mead Wildlife Area by felling individual trees to provide better spacings between trees and for efficiency in collecting the cones once the tree tops were on the ground. 21 white spruce were harvested and 15 bushels of cones collected from their branches, resulting in 14 lbs. of seed. Future harvests will likely follow this model, as it is impractical to collect cones from the older seed orchards without having to harvest individual trees.

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 300,000 seedlings annually the state nurseries require about 4 pounds of seed/year. We anticipate that a total of 5 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.

Future Program

The white spruce program will be **maintained** in the Strategic Plan for 2019-2029 at current levels for improvement and conservation. Our most immediate need involves the completion of a grafted clonal seed orchards using the best selections currently available in the three older orchards. Plans have been made to begin white spruce grafting in early 2020. The Hayward Nursery has land and staff that could provide for maintenance and management once grafted trees are available. We expect to overcome the high cost of collecting seed from large trees by managing smaller height-controlled orchards, e.g. Hayward, through pollarding. It is also anticipated that the completed Hayward orchard could supply enough seed to eliminate the need for general collections from wild stands.

Black Walnut

Status in Wisconsin Forests

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. The total volume of black walnut timber has increased six-fold since 1983. It represents less than 1% of total timber volume due to its limited range (mostly southwest and southeast Wisconsin) and the limited number of sites suitable for its establishment and growth. It occurs primarily on upland sites mixed with other hardwoods, especially oak and hickory.

During the past two decades, demand for black walnut planting stock has dropped considerably, averaging from 130,000-170,000 seedlings per year to 75,000 per year.

Thousand Cankers Disease, a serious fungal disease for walnuts, results from the combined activity of the fungus, *Geosmithia morbida*, and the walnut twig beetle, *Pityophthorus* juglandis, which carries it. There is concern for the possibility of it spreading into the state and threatening the population of black walnut here. It has not been detected in Wisconsin at this time.

Potential

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.[26] 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.[27] 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.[28] This underscores the need for a conservative approach to the use of non-local sources of black walnut.

History of the Program

A five-acre family test/seedling seed orchard was established at Wyalusing State Park (Grant Co.) in 1978 with 114 families from Wisconsin, southeast Minnesota, Indiana and northern Illinois. The orchard no longer exists, but data collected in the 1980s indicated seedlings from Wisconsin and northern Illinois were better adapted and had superior performance than seedlings from Minnesota and southern Indiana.[29]

In 2004, a 10-acre site was identified on the Kickapoo River Wildlife Area, Bell Center Unit (Crawford County) for a grafted black walnut seed orchard. Starting in 2006 and continuing through 2015, over 200 grafted clones of phenotypically superior black walnut from natural stands in Wisconsin and northern Illinois have been out-planted here. The Bell Center Orchard, which besides the black walnut includes grafted red oak and butternut seedlings, is protected from deer by an 8’ woven-wire fence installed in 2017. The orchard serves to conserve the limited genetic resource of black walnut that is adapted to Wisconsin and provides a source of improved seed for the state nursery program.

Available Plant Resources

The best source of additional materials for future improvement efforts in Wisconsin will be wild stands in the northwest part of the species range, as well as the material already conserved at the Bell Center Orchard.

Traits to Improve

Stem form and growth rate are the two traits of greatest interest in black walnut tree improvement. Thousand canker disease is a potential threat to black walnut in Wisconsin if it spreads from areas to the east or west, so there is interest in any available resistance that may be identified.

Seed Production

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.

Future Program

The black walnut program will be **maintained** in the Strategic Plan for 2019-2029 at current levels for improvement and conservation. The grafted walnut at Bell Center have started to produce walnuts, and these are collected for the state nursery at Boscobel as needed.

Butternut

Status in Wisconsin Forests

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. It 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, and these tests indicate that there is a wide phenotypic variation in susceptibility to the disease.[30] None have proven resistant, although a few may have modest levels of tolerance to the fungus. 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 extirpation from the state.

Some trees which appear to be butternuts are actually hybrids. Native *Juglans cinerea* easily hybridize with at least two exotic species, Persian or English walnut (*Juglans regia*) to form *Juglans x quadrangulate*, and Japanese walnut (*Juglans ailantifolia*) to form *Juglans x bixby*.[27] In some places, these hybrids or their offspring are virtually the only "butternuts" to be found.[28] Hybrids are typically more resistant to butternut canker than native butternuts, are vigorous, and produce large numbers of nuts. There are concerns that if hybrids continue to proliferate in forests within butternut's range, they would "pollute" the gene pool, and may replace the native genotype with trees containing non-native genes. However, hybrids could offer a source of disease resistance or tolerance, and may be the only viable means to retain butternut in the landscape if resistance is not identified in native material.

History in the Program

In 2010, 74 butternut bareroot progeny seedlings were planted at the Bell Center Seed Orchard. The seedlings were from the USFS Hardwood Tree Improvement Regeneration Center (HTIRC) at Purdue University in Indiana, and came from nuts of native butternut trees mostly sourced from Wisconsin. The seedlings were planted as a trial to look for resistance or tolerance to butternut canker in 'pure' native butternut. Results from this trial have been inconclusive due to repeated buck rubbing on the trees, causing severe damage. A new woven-wire fence was erected at Bell Center in 2017, so the orchard is now protected from deer.

A 1-acre grafted butternut orchard was planted in 2013 at the Hayward Nursery. This consists or grafts made at the Oconto River Seed Orchard from Wisconsin sources that demonstrated putative resistance to butternut canker. Of the original 68 grafted trees planted, 30 have survived. This planting has not yet been rated for canker tolerance.

Present Program

The orchards at Bell Center and Hayward have been well-maintained and the more durable and effective fence installed. Preparations are underway for a new butternut canker trial discussed below.

Available Plant Materials

Clone banks of putatively resistant selections have been made by the USFS. Wisconsin selections available to our program are currently located at their Northern Research Station, Hardwood Tree Improvement and Regeneration Center and Oconto River Seed Orchard.

Traits to Improve

Resistance and tolerance to butternut canker disease has been the primary focus of improvement due to the threat it poses to the species.

Future Program

Butternut will be **maintained** in the program, though the managed acreage will be increased. In 2018, the Wisconsin Reforestation Program was approached by USFS researchers working to identify resistance to butternut canker in butternut of native genotypes. They have planned a 5-acre trial of native butternut seedlings, using material collected by HTIRC, to definitively determine whether resistance or tolerance exists in the native species. This new planting will supplant the relatively small and damaged trial located at Bell Center and replace it with a more extensive trial. USFS will provide the funding for additional fencing, design and plant the trial, and do the data collection. Wisconsin Reforestation and Tree Improvement will prepare the site for planting, sow an understory cover crop to reduce volunteer growth, contract out for the added fencing, and perform regular maintenance tasks. Planting of the seedlings is scheduled for May of 2019.

The Wisconsin DNR is interested in this trial, as it will help forecast the fate of native genotypes in the state and inform future reforestation practices. If it is determined that native butternut has no resistance to the canker, and the future of the species in Wisconsin forests is in question, then it may be possible to look at hybrids and their offspring as replacements for *J. cinerea* in Wisconsin forests.

The orchard at Hayward needs to have the grafted material that did not survive replaced, especially in cases where there were no survivors in a particular family. Discussion is underway to determine the feasibility of expanding the area where we wish to plant grafts of putatively resistant native genotypes. This orchard can act as an important conservation area for native genotypes which are rapidly disappearing from the landscape, and possibly be a source of butternut tolerant to canker for reforestation purposes.

Northern Red Oak

Status in Wisconsin Forests

Northern red oak occurs throughout the state, predominately in northwest and southwest Wisconsin, on dry-mesic and mesic sites. The number of northern red oak trees has declined since 1996 in all class sizes, but especially in pole-sized trees. It is an important timber species in Wisconsin.

History of the Program

Between 2004 to 2007, 248 red oak grafted trees were planted at the Bell Center Orchard. The scionwood was collected from phenotypically superior trees located around Wisconsin. The orchard will be used for seed collections and as a conservation planting of red oak genetics from various Wisconsin locations.

Present Program

The red oak at Bell Center have yet to produce acorns, but the orchard is being maintained and will become a seed orchard for acorns of diverse genetic backgrounds when the trees do start to produce seed.

Future Program

Northern red oak will be **maintained** in the program. There is some question whether the graft unions of red oak succeed over time, though there is no evidence of widespread graft failure yet at Bell Center. There are no plans to add to the trees that are already being managed in the program.

New Initiatives

In a dynamic reforestation climate, opportunities often arise that do not fit in with traditional tree improvement protocols. However, as different products are sought, it behooves staff to adjust to the market. The following are some areas that may be explored in the coming years to determine if tree improvement techniques can be a benefit.

Assisted Migration

A relatively new, and sometimes controversial, climate change adaptation strategy is assisted migration. This strategy involves the human-assisted movement of species to suitable habitats in response to climate change. Assisted migration may include three levels of movement:

- *Assisted Population Migration* – moving individual genotypes within a species' native range
- *Assisted Range Expansion* – moving a species to areas just outside of their native range, mimicking natural range expansion
- *Assisted Long-Distance Migration* – moving species to areas far outside their native range

Assisted migration trials in Wisconsin have been generally conservative, involving limited population migration and range expansion. Southern Wisconsin seed sources of bur and white oak have been planted in trials in northern Wisconsin. American sycamore seedlings have been planted slightly north of their southern Wisconsin range for bottomland hardwood plantings in central and western Wisconsin. Several questions remain about the long-term adaptability and performance of moving species and genotypes. Past tree improvement research (e.g., provenance tests) may help inform these questions for some commercial species. However, many species have limited genetic performance data. The Wisconsin Tree Improvement Program does not have the resources to research these questions alone but will support work to further the science behind finding successful climate change adaptation strategies.

- Provide technical assistance to foresters/researchers establishing assisted migration trials
- Develop guidelines for movement of species and genotypes based on best available science

Insect and Disease Resistance Breeding

Over the past few decades, forest genetics and tree improvement activities have declined, particularly in the eastern U.S.[29] where forests are under attack by invasive insects and diseases to which the host populations have low levels of resistance. Breeding trees for genetic resistance can be an effective management tool, and in many cases, it may be the only tool to help restore and maintain our forests. Due to the critical need for genetic resistance programs, the establishment of an Eastern States' Coalition for Forest Tree Breeding is proposed to provide a framework for states to share costs, increase efficiency through coordination, and establish the continuity that is vital for the success of such programs. Organizers have developed a draft structure for the coalition and are approaching the Northeast and Midwest State Foresters Alliance and the Southern Group of State Foresters for their approval and engagement. Improvement projects will be focused on resistance to invasive pests and diseases. Funding would initially be raised from participating states, $10,000 per year for three years for full participants with the goal to develop permanent funding through an endowment unaffected by government budget cycles. The annual funding target per tree species/pest pair is $200,000.

The program to develop resistant stock will include three phases. During the research phase, studies are conducted to detect and confirm resistance to a new insect or disease and to develop a breeding strategy. In the technology transfer phase, potentially resistant trees are identified, controlled breeding conducted, and propagation initiated. In the operational phase, planting stock is grown and restoration plantings conducted. States would participate in these three phases according to their resources for the project including: presence of stands of host trees that have been winnowed by the invasive organism, facilities for propagation or testing, and staff with experience in tree improvement and propagation. This coalition could and should include current or developing state and multi-state breeding programs for invasive pest and disease resistance.

Seed Production Areas (SPAs)

Seed production areas are generally natural stands of trees (sometimes plantations) that have been rogued and/or prepared for seed collection purposes. SPAs provide a seed source with known geographic origin and phenotypic qualities. Limited genetic improvement is expected because the trees are rarely progeny tested. SPAs can be especially useful as a source of well-adapted seed at a modest cost (Zobel and Talbert 2003).

In the past, Wisconsin has made only minor investments in SPA development. Previous efforts include the identification of potential areas for black walnut, red oak, and swamp white oak. Considering the greater program focus on species adaptability (rather than strictly genetic gain), seed zone management, and cost effectiveness, some species will be well-suited for continued SPA development, including:

- Black walnut
- Northern red oak
- White oak
- Swamp white oak

Silviculture and Genetic Field Trials

The DNR documents silviculture trails conducted by field foresters in Wisconsin. These trials cover a wide variety of silvicultural treatments, including novel approaches in reforestation, prescribed burning, scarification, thinning, etc. Reforestation trials testing new species, genotypes, stock types, and planting methods are supported by the Reforestation and Tree Improvement Programs. Examples of silviculture trials with a reforestation component include bottomland and swamp hardwood EAB restoration planting, elm reforestation, Southern Appalachian white pine, and lowland underplanting. The Wisconsin Tree Improvement Program will continue to support silviculture trials, particularly trials utilizing and testing new species and genotypes, including:

- Bottomland and swamp hardwood restoration planting
- Climate adaptation trials

Urban Planting Stock

Through anecdotal evidence (professional conversations between DNR Urban Forestry [UF] Coordinators and municipal foresters) and data collection (WI-DNR Community Tree Map), it was determined that a majority (60%) of landscaped sized trees (1 ¼" – 2"+ caliper) planted in Wisconsin's urban/community landscapes, i.e. boulevards/terraces, parks, business parks/campuses and residential properties are comprised of only five tree Genera (*Acer spp*. 31%, *Fraxinus spp*. 14%, *Gleditsia spp*. 7%, *Tilia spp.* 5%, and *Celtis spp*. 3%).

Typically, the reason given for the low species variety is the limited supply offered available from private nurseries. Unfortunately, this almost monotypical situation can give rise to major catastrophes, similar to the mass mortality of American elm due to the invasion of Dutch elm disease (DED). In order to avoid these situations, it is desirable to increase the diversity of mature trees, which necessitates an increase in diversity of available stock.

Also, through viewing recent Plant Hardiness Zone Maps it is known that overall temperatures are increasing over time, we must prepare and adapt so Wisconsin communities where 80% of our population lives will have a vibrant and sustainable tree canopy to mitigate storm water, decrease energy use and help create a healthier and active population. Through testing and propagating lesser used tree species known to prosper in warmer climes we can achieve this.

Some of the proposed initiatives may include:

1. Utilizing surveys to determine species of interest amongst private and public urban forestry professionals and utilize nursery trials to determine the viability of propagation and production. This information could then be shared with private nursery for their use.
2. Utilize open WDNR nursery facilities to experiment with tree species ability to adapt to an urban condition.

White Oak Cooperative

White oak is a relatively common tree occurring in upland forests across much of the east central US. It has intrinsic value to wildlife and is also economically valuable for a variety of markets including high-end products such as flooring, cabinetry, veneer, and barrel staves for distilled spirits. In recent years, forest inventory assessments have indicated that oak regeneration will be insufficient to meet future demands for these markets, especially for the bourbon industry. This lack of natural regeneration is mainly attributed to silvicultural practices, or a simple lack of forest management, that are insufficient to meet the high-light intensity demands associated with natural white oak regeneration. Markets for white oak timber, especially veneer and stave logs, remain strong to the point that log buyers have expanded their search for high quality logs across a total of 23 states in both the southern and central US. A new program, the White Oak initiative (WOI), being led by the University of Kentucky in Lexington, is actively engaging stave mills and the distilling industry to raise awareness about the need for both better silvicultural practices across the region and, to improve the genetic resources of future white oak plantings using applied tree improvement approaches.

White oak is native to the southern half Wisconsin. The Wisconsin DNR is considering increasing production of seed orchards to provide a seed source to serve the northern part of the native range of white oak in the state, to help ensure a future forest resource that is not only well-adapted, but also of known genetic origins and quality.

Eastern White Pine Specific Gravity

The specific gravity of white pine is inadequate for its use in cross-laminated timber. If work to identify or breed for higher density in white pine were done, it could potentially raise the value of white pine timber significantly for the fastest increasing tree species in Wisconsin.

Appendix

Glossary

<u>Seed zones</u>
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; 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.

<u>Seed collection areas</u>
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.

<u>Seed production areas</u>
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.

<u>Seed orchards</u>
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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