UNIVERSITY OF MINNESOTA
College of Natural Resources
Department of Forest Resources

MINNESOTA TREE IMPROVEMENT COOPERATIVE

2004

ANNUAL REPORT

Carolyn C. Pike	James C. Warren	Andrew David
Coordinator	Research Fellow	Director

January 3, 2005

MEMBERS
Beltrami County
Cass County
Crow Wing County
Iron Range Resources
Itasca County
Itasca Greenhouse Inc.
Koochiching County
Lake County
Minnesota DNR
  Division of Forestry
Plum Creek Timber Company
Potlatch Corporation
Red Lake Nation
St. Louis County
UPM-Blandin
University of Minnesota,
  Department of Forest Resources

SUPPORTING MEMBERS
Carlton County
Clearwater County
Hedstrom Lumber Company
Hubbard County
Minnesota Nursery and Landscape Association
Pine County
Wausau Paper

TECHNICAL ADVISORS
USDA Forest Service State and Private
  Forestry
USDA Forest Service North Central Forest
  Experiment Station
University of Minnesota
  College of Natural Resources

EXECUTIVE SUMMARY

The Minnesota Tree Improvement Cooperative entered its twenty-third year in 2003 with sixteen full members and six supporting members. Total dues received was $56,940. Two business meetings were held, one on January 23rd and another on March 28th. The annual fall workshop was held on Sept 17, 2003. The Co-op was directed by Dr. Andrew David, and coordinated by Carrie Pike from the University of Minnesota's Cloquet Forestry Center. Jim Warren, Research Fellow, worked part time for the Co-op assisting with field tasks and office work.

Priorities for 2003 included planting three replications of a second-generation white spruce population, six replications of a white spruce comparison trial and three replications of a range-wide provenance trial of white pine. Controlled pollinations were made at St. Louis County's white pine orchard and resulted in 32 new crosses. Visits were made to 45 Cooperative plantings/orchards by Pike and Warren. Tree heights, diameters, stem form and gall rust incidence were collected from two replications of the five-year old second-generation jack pine plantings. Heights and diameters were taken from one replication of a 25-year old range-wide provenance trial of black spruce. Incidence of blister rust disease was assessed at three replications of a field-test of white pine. A white pine progeny test in Tofte, planted in 1972, was also re-assessed and cones collected for screening. The remaining seedlots of second-generation white spruce were sent to Potlatch's tree nursery and were seeded and germinated in September.

Pike attended two seminars in Canada, and three in Minnesota. A poster was presented at two meetings and Pike presented at the DNR silviculture meeting in December. Pike had two publications in Better Forests, one in Northern Journal of Applied Forestry. An article by David/Pike/Stine appeared in Theoretical and Applied Genetics. An article by Jurgens et al. was published in Plant Disease in 2003.

Outlook: in spring 2004 test-crosses will continue to be made among un-tested genotypes of white pine. Pollen will be collected from select individuals in the second-generation jack pine populations for producing test-crosses. Orchard management needs to be intensified at a number of orchards, which includes better utilization of $GA_{4/7}$ and fertilizer to maximize cone production. Crown management, particularly for red pine, needs to be implemented to increase the availability of cones. In addition, increased monitoring and management of cone/seed insects will need to be addressed before insect populations become destructive.

Table of Contents

INTRODUCTION

The Minnesota Tree Improvement Cooperative has now entered its 23rd year, and remains committed to the genetic improvement of conifer species in the upper Midwest. During 2003, 16 full members and 6 supporting members provided funding to support the Co-op. First-generation seed orchards are in place for five conifer species: black spruce, white spruce, jack pine, red pine and white pine. In addition, second-generation seed orchards are in place for black spruce, white spruce and jack pine.

High priority activities for 2003 included planting three replications of a second-generation white spruce population, six replications of a white spruce seed source trial, three reps of a white pine range-wide provenance trial and making controlled crosses in white pine. All but four actively managed Co-op seed orchards were visited in 2003.

This report describes the Co-op's program and summarizes activities and accomplishments from January 1 to December 31, 2003. It is organized into five sections: Administration, Finances, Seed orchards, Species reports, and Outlook.

ADMINISTRATION

Carrie Pike remains Coordinator of the Co-op, operating out of the University of Minnesota's Cloquet Forestry Center. Jim Warren continues to work a split-time appointment between the white pine grant, MTIC, and Ag Experiment Station (AES) funds, through the Department of Forest Resources.

Dr. Andy David, Director, continues to assist with long-term directives and consultation. His time is divided between the Aspen/Larch Genetics Cooperative in Grand Rapids, the Minnesota Tree Improvement Co-op in Cloquet, and teaching duties in St. Paul. Kathy Haiby and Egon Humenburger, operating out of Grand Rapids, are partially funded by the white pine grant as well, and are paid to assist on work pertaining to the genetic improvement of white pine.

The Advisory Committee consists of representatives from each member of the Co-op. It met twice during 2003 for business meetings, once on January 23rd at the Cloquet Forestry Center and again on March 28th at the U of M's North Central Research and Outreach Center (NCROC) in Grand Rapids, MN. The Fall Workshop entitled "Artificial Regeneration and the Role of Tree Improvement in Minnesota and Wisconsin" was held on Wednesday, September 17th at NCROC. Speakers included Paul Charrette of the Superior-Woods Tree Improvement Council in Thunder Bay as well as Jean Perkins, Forest Silviculturist from the USDA Forest Service in Duluth. In addition, eight members of the Advisory Committee spoke about the trials and tribulations of their planting programs. Registration for attendance was $15, which covered the cost of the lunch provided.

On-site visits were made to 45 different Co-op plantings in 2003 by Pike and Warren. In addition, travel expenses covered Pike's attendance at the SAF winter meeting in February and LUSTR Forest Renewal Co-op workshop in Dryden Ontario. Pike and Warren attended the annual workshop of the Superior Woods Tree Improvement Co-op in Fort Frances (Ontario), annual stock tour at Badoura Nursery, and the North Central Forest Pest Workshop held at the Cloquet Forestry Center. Pike spoke to students from Vermilion College about tree improvement during their annual visit to CFC, to fifth graders at the SAF field days in Duluth, and to students at Arbor Day Celebration in Chisholm. In addition, the following articles were published (U of M constituents are in **boldfaced** type):

David A., C. Pike, R. Stine. 2003. Comparison of selection methods for optimizing genetic gain and gene diversity in a red pine (*Pinus resinosa* Ait.) seedling-seed orchard. Theoretical and Applied Genetics, 107: 843-849.

Jurgens, J.A., R. A. Blanchette, P.J. Zambino **& A. David.** 2003. Histology of white pine blister rust in needles of resistant and susceptible eastern white pine. Plant Disease, 87: 1026-1030.

Pike, C. 2003. Artificial vs natural regeneration: The first in a two-part series about reforestation in Minnesota. Better Forests, 8(1): 18-21.

Pike, C. 2003. Artificial regeneration vs natural regeneration: The second in a two-part series about reforestation. Better Forests, 8(2): 12-13.

Pike C., D. Robison, C. Maynard and L. Abrahamson. 2003. Evaluating growth and resistance of eastern and western white pine to white pine weevil and blister rust in the northeast. Northern Journal of Applied Forestry, 20(1): 19-26.

SEED ORCHARDS

Seed orchards are the primary means by which the Co-op produces genetically improved seed for use in commercial-scale planting programs. Since 1967, members of the Co-op have established 59 seed orchards, of which 52 are still used for seed collection. All first generation jack pine orchards and five of eight red pine orchards have been rogued. A summary of the types and sizes of orchards managed by members of the Co-op is shown in Table 6. Table 7 lists all orchards by species and owner.

Table 1. Acres of seed orchard by species and orchard type.

Type	Black spruce	Jack pine	Norway spruce	Red pine	White pine	White spruce	Total acreage
First Generation Seedling Seed	8.2	23.2		42.2		4.1	77.7
First Generation Clonal	7.6		0.6		13.3	25.6	47.1
Second Generation Full Sib	3.5	6.4				5.7	15.6
Total by Species	19.3	29.6	0.6	42.2	13.3	35.4	140.3

Cone Collections

In 2003, cone crops for most tree species were small. St. Louis County collected the first sizeable cone crop since roguing from its **Ellsburg Rd** red pine orchard. The cone crop was likely positively impacted by fertilization and/or treatment with $GA_{4/7}$ in 2001. The effects of fertilization were also evident at **Potlatch's Gillogly Rd** red pine orchard, which had a moderate cone crop. White spruce cone crops were highly variable in 2003.

Table 2. Cones collected by MTIC Cooperators in 2003.

Species	**Cooperator, orchard**	**No. bushels**
White spruce	Blandin, Arbo	1.25
	Blandin, Latimer	7.25
Jack pine	Potlatch, Gillogly Rd	8.0
Red pine	Potlatch, Gillogly Rd	10.0
	St Louis Co, Ellsburg Rd	14.0
White pine	St Louis Co, Ellsburg Rd	7.0

SPECIES REPORTS

Black spruce

Status

Currently, demand for improved black spruce seed is low since most cooperators rely on aerial seedling woods run seed to regenerate black spruce. There is interest in addressing whether or not improved seed collected from Co-op orchards should be used in aerial seeding programs. Following an extensive literature review, a project may be developed to investigate the costs of using improved seed in aerial seeded plantings in Minnesota.

In winter 2003 Pike and Warren collected scion material from the **Koochiching County Big Falls** black spruce orchard and approximately 100 grafts were made at Itasca Greenhouse. These grafts are slated to be planted in **Koochiching's Larsaybow** seed orchard. Survival of the grafts was lower than expected, and future grafting may be postponed until better success can be guaranteed.

Visits to **DNR's Eaglehead** and **Blandin's Blackberry** seed orchards were made in 2003. Both orchards are well maintained, and utilized for periodic seed collection. Pike also visited **DNR's Split Rock** second-generation orchard, and the **DNR's Sturgeon Lake** grafted seed orchard. Both orchards have started to produce cones, but to date none have been collected.

The MTIC is cooperating with Lakehead University (Thunder Bay) and the Canadian Forest Service to re-measure a range-wide black spruce provenance trial, which was planted 30 years ago. Two of these plantings reside in Minnesota. Pike and Warren spent four days measuring one trial in Grand Rapids, MN. The second trial is in Rosemount, MN (south of the Twin Cities), and will be measured by spring, 2004. These trials were established in a cooperative project between the Canadian Forest Service, Lakehead University, University of Minnesota and the USDA Forest Service. It was the basis of early selections in North American tree improvement work for black spruce. Our participation ensures that MTIC will have direct access to results, being analyzed by researchers at Lakehead University.

Short and long-term planning

Grafting techniques need to be analyzed and perfected if more grafting is to be attempted. The current MTIC Coordinator is exempt from all future grafting due to pathetically low survival of grafts produced by her hand. Management recommendations for several orchards are as follows: **Blandin's Blackberry** orchard should be periodically topped; and cones should be collected from **DNR's Split Rock**, **Koochiching's Larsaybow** and **Big Falls** seed orchards. **DNR's Sturgeon Lake** requires thinning in the near future.

With most orchards now producing ample quantities of seed, which generally go unpicked, the question of how best to utilize this seed is being raised. The cost of collecting improved seed and maintaining seed orchards currently prevents the use of orchard seed in aerial seeding applications. If the costs of collecting improved seed for aerial seeding can be justified, then the demand for improved black spruce seed will increase significantly in the future.

White spruce

Status

White spruce has been a priority species for the MTIC in the past several years. Great progress has been made, and now the Co-op is poised to once again shift project emphasis into *Pinus* spp. In 2003, improved first-generation orchards were established at **Potlatch's Gillogly Rd** and preparations for planting at **Red Lake Nation's** new **Redby** orchard were made. Additional grafts were added to the **MN DNR's Split Rock** planting and in **Blandin's College** seed orchard. Three replications of second-generation material were out-planted in May, 2003. The plantings are managed by **Itasca County** "**Wabana Lake**," **MN DNR** "**Eaglehead**" and **St. Louis** "**Ellsburg Rd East**." Each site contained 16 reps of 56 new full-sib crosses, resulting from breeding work in 1998 and 2000.

Also in spring 2003 five replications of a white spruce comparison trial were planted which included six seed sources: a rogued orchard of Minnesota sources, seed from the top two performing individuals at the same orchard ("high gain material"), a rogued orchard of Ontario sources, un-rogued orchard of Ontario sources, woods run material, and genetically improved black spruce. Five cooperators set aside roughly five acres each from a commercially prepared site for inclusion in the study. The sites are owned by **Koochiching County**, **MN DNR**, **St. Louis County**, **Blandin**, and **Potlatch,** and are located near Little Fork, Hibbing, Duluth, Coleraine, and Brookston, respectively.

Short and long-term planning

Additional grafting will likely be necessary to make up for the poor survival of grafts planted prior to the very snowless winter of 2002. However, no plans are set to graft in winter 2003. Survival will need to be assessed at all sites with new grafts in summer 2004, and grafting in 2004-2005 may be necessary. Comparison trials planted in 2003 should be surveyed for overall survival. Sites with good survival should be monumented with wooden stakes at block intersections in spring/summer 2004. New second-generation plantings should be monitored for survival, and maintained to reduce competition.

In fall 2003, seed from an additional 120 crosses was sown at Potlatch tree nursery in Cloquet for out-planting in spring 2005. This seed is the second half of the second-generation white spruce that was planted in May, 2003. A similar design (16 blocks per site, roughly 110 families at each of three sites) will be used, and one site each will be planted in Grand Rapids (**Blandin**), **Lake County**, and adjacent to the **MN DNR Eaglehead** white spruce. Planting sites should be selected in 2004 and prepared by fall 2004. Measurements of second-generation material will take place every five years. Once the seedlings approach maturity in 10-15 years, test-crosses should be made to evaluate the parents in a progeny test.

In addition, if time permits, additional data on bud-break timing of different sources of white spruce should be collected to supplement data collected in 2001 and 2002. This data may prove valuable in showing how bud-break timing and subsequent growth patterns vary among sources.

Jack pine

Status

Jack pine orchards continue to be heavily utilized for cone/seed collection. Nearly all orchards listed in Appendix B have been topped and are picked periodically. Not listed in Appendix B, **Potlatch's Kallstrom** orchard has been abandoned for several years, but was a benchmark site of early research on jack pine and remains an important relic of the MTIC program. Pike and Warren visited it this spring and were able to locate tags on the now very large trees.

Staff at **Red Lake** have been busily reclaiming the formerly abandoned **Redby** seed orchard. Old maps were retrieved, and a new map of surviving trees was made. Height, diameter, stem form, and gall rust measurements were taken from surviving trees in preparation for rouging in 2004.

In **Calumet**, **IRR** replaced worn tags and surveyed the orchard to account for mortality. In Carlton at **Potlatch's Gillogly Rd**, trees have rebounded from topping and have produced a sizeable (and very accessible) cone crop, which was collected in 2003.

At **Wausau-Mosinee's Barnes** orchard, near Solon Springs Wisconsin, trees topped in 2002 have recovered nicely, and continue to produce cones annually. **St. Louis's Ellsburg Rd** and **MN DNR's Longprairie** orchards are well managed and manicured, and are picked almost annually. **MN DNR's Nickerson** orchard has not been highly managed but is slated for future clean-up. Next year's visits will include **Crow Wing**'s first generation orchard.

Two of the original four second-generation plantings have excellent survival. These will become the primary source for future generations of jack pine improvement.

Short and long-term planning

Five-year measurements were collected from the two remaining second-generation plantings (**Crow Wing County/ MN DNR's County Line** and **St. Louis/IRR's Ellsburg Rd. East** plantings). Data is currently being analyzed and tentative results are shown in Appendix C. Both second-generation sites had a substantial cone crop, and crosses will be made in these orchards as soon as 2004. Seed from these crosses will be planted as a progeny test in the future. A progeny test will serve to identify the best "general combiners," or individuals that will make the best parents for an improved second-generation seed orchard.

Jack pine regeneration has become limited by deer browse in many Counties in western Minnesota. However, the need for improved seed will increase as the DNR increases cutting of over-grown jack pine forests and utilizes artificial regeneration to reclaim them. In the past year demand for improved seed has outweighed availability for some Cooperators.

Red pine

Status

Red pine orchards are starting to produce cones on a regular basis, but cone collections remain a costly endeavor. A sizeable cone crop at **St. Louis County's Ellsburg Rd** was picked this fall. The **MN DNR's Eaglehead** and **Cotton** orchards had a moderate cone crop. **Plum Creek Timber Company's Ashwabay** orchard also had a moderate cone crop. **Potlatch's Gillogly Rd** had a low to moderate crop, which was collected. Repeated fertilizing with heavy amounts (500#/acre) of ammonium nitrate appear to have increased the cone crop at **Gillogly Rd**. However, the incidence of cone/seed insects is rising and some form of control may be needed in the future.

Cass-Beltrami-Hubbard County's Blind Lake orchard, located near Backus, was visited for the first time since 1999 and survival there is excellent. Blind Lake should be measured in fall 2004 and rogued as soon as 2005. Survival at **Wausau Mosinee's Mosinee** orchard has leveled off since early mortality due to grubs. That site will continue to be visited annually, and will likely be measured in fall 2005 or 2006. Next year a visit to **Plum Creek Timber Company's Petenwell** orchard will be made, and that orchard is one to two years away from measuring/roguing as well.

Short and long-term planning

Red pine remains the most highly planted tree in Minnesota. In 2003 state nurseries were challenged with *Sphaeropsis* fungus, which decimated seedlings after out-planting in spring 2003. Demand for improved seed is still not being met, and will only increase, as red pine is favored over jack pine in areas with heavy deer browse.

The most likely next step for tree improvement will be the establishment of new improved first-generation orchards for this species. Grafting of this species should begin in earnest as grafted orchards offer the best chance to reduce the time to seed. Secondly, crosses among top-performing individuals should be made to test general combining ability. In addition, a trial to compare improved vs woods run sources is planned for the near future, but no timetable has yet been set.

White pine

Status

White pine orchards remain in good standing, being highly productive and relatively easy to crown-manage. **MN DNR's St. Francis** orchard had a highly productive cone crop in 2002, but had few cones in 2003. Many of those trees are growing rapidly and responded well to topping. **Rajala & Itasca County's Bass Lake** orchard is also showing excellent growth under highly intensive management. A sizeable cone crop was observed this fall, but no cones were picked. **St. Louis County's Ellsburg Rd** has had some difficulty with pine adelgid, as has the U of Minnesota's CFC breeding arboretum. The young grafts at **St. Louis County's Ellsburg Rd. East** had an abundant cone crop, making for 32 easy cross-pollinations by Pike and Warren in spring 2003. Pike and Warren visited the site where **Itasca Greenhouse** plans to build a new grafted orchard of white pine, with grafting starting as soon as winter 2004. In addition, **Red Lake** identified ten plus-trees from the reservation that will be the source of scion material for a new grafted orchard. This orchard will likely be located adjacent to the new white spruce orchard just south of Redby.

Short and long-term planning

Deer browse remains a serious constraint to regenerating white pine in many areas, owing primarily to the mild winters of previous years. Underplanting and planting white pine in mixed, open grown plantations are the primary methods of artificial regeneration. State funding, which assisted county and state cooperators with regeneration of white pine, dried up in 2003. This will limit the resources available to practice measures such as bud-capping on public land.

Crosses will continue to be made in the CFC breeding arboretum and at cooperator orchards as inflorescens are available. Seed will be screened for blister rust susceptibility in St Paul and parents eventually rogued from the orchard if they demonstrate high levels of susceptibility.

Pike, Warren, and Haiby spent approximately seven days in Tofte re-evaluating the white pine test that was planted by Cliff Ahlgren in 1973. Cones collected from approximately 50 trees were opened, and seed extracted by Haiby in fall 2003. This seed will be sent to St. Paul to be evaluated in the screening process established by Zambino and Blanchette. All trees are being measured and re-assessed for blister rust. An analysis is being conducted to identify families with potential major gene resistance.

Three USFS progeny tests will be measured fall 2003 into winter 2004. Data from these sites will be combined with observations from previous measurements and used to evaluate families in Co-op orchards that originated from the USFS plus-tree program.

OUTLOOK

Currently, public agencies are facing serious financial constraints that may ultimately affect membership in the MTIC. Despite the gloomy forecast, most members anticipate renewing in 2004. The decision to uphold membership status is bolstered by the favorable results seen in recent comparison trials, reiterating the importance of testing seed orchard material and demonstrating the authenticity of estimated genetic gains. MTIC members are un-wavering in their support for tree improvement. All improved seedlings that are grown in Minnesota state nurseries are sold or planted by the DNR, and demand typically exceeds supply. An adequate supply of improved red pine seed has yet to be secured, but there is also an anticipated surge in the need for improved jack pine seed as old, over-mature stands are renewed and rejuvenated.

A new forest productivity Co-op is in the early stages of development, signifying the commitment of forest agencies to the maximization of wood production. A governor's task force met in 2003 to define measures that would make Minnesota's forest industry more globally competitive. One important recommendation was to improve forest productivity, an area to which improved seed is well suited.

The Co-op has three major goals for 2004: (1) fine-tune seed orchard management by implementing strategies to increase cone production, (2) continue with breeding program for white pine and jack pine, and (3) devise strategies to maximize the utilization of improved seed on planted and aerial-seeded lands.

Field-work in spring 2004 will consist entirely of making test-crosses among untested genotypes of white pine as well as among select individuals from the second-generation jack pine populations. Orchard management needs to be intensified at a number of orchards, which includes better utilization of $GA_{4/7}$ and fertilizer to maximize cone production. Crown management, particularly for red pine, needs to be implemented to increase the availability of cones. In addition, increased monitoring and management of cone/seed insects will need to be instituted before insect populations become destructive.

A workshop "Stock-type Selection and Field Handling of Forest Tree Seedlings" is planned for March 11, 2004 at the Cloquet Forestry Center. In this workshop, procedures for proper stock handling to improve the success of forest tree plantings will be addressed.

2004 COOPERATIVE WORK PLAN

Black spruce:
- Plant grafts into Larsaybow
- Address question about aerial seeding: comprehensive literature review followed by possible trial establishment
- Complete measurements at Rosemount provenance trial

White spruce:
- Plant grafts into white spruce orchards (DNR, Red Lake, Potlatch, Lake Co.)
- Mortality survey of 2003 comparison trials, stake as needed
- Mortality survey of 2003 second-generation plantings
- Bud-break trial – further investigations?
- Measure 1995 comparison trials (U of Minnesota Cloquet Forestry Center and Potlatch - Hill City)

Jack pine:
- Make crosses among second-generation families if flowers are available
- Complete analysis of fifth-year second-generation planting data
- Begin grafting? (DNR)

Red pine:
- Collect seed for comparison trial
- Measure and prepare to rogue Cass-Beltrami-Hubbard red pine orchard
- Visit Plum Creek Timber Company's Petenwell orchard

White pine:
- Make controlled crosses as flowers are available
- Maintain breeding arboretum
- Add additional ramets to breeding arboretum
- Continue work at Tofte
- Finish USFS progeny test measurements (winter)
- Start field grafting at Bass Lake (2004 or 2005)
- Start grafting for Itasca Greenhouse seed orchard
- Collect seed or scion from plus-trees at Red Lake

APPENDIX A

Explanation of IRS tax

A tax of 7.5% is applied to all "income" that comes into the University of Minnesota and is referred to as IRS (Internal Revenue Sharing). This tax is used to cover general overhead costs at the U such as computers, email, libraries, etc. This tax was first instated in FY 2000 and is now applied to all dues as well as workshop registrations. Grants are exempt from this tax, thus the MN DNR contract and the white pine grant are not taxed. Details about the policy can be found on the Twin cities website via the link: http://www.fpd.finop.umn.edu/groups/ppd/documents/policy/assessing_revenue.cfm#430

The section "Reason for Policy" is shown below:

"The "sales and services" portion of the IRS was created to recognize that external purchasers of University goods or services can be expected (through the rates they are charged) to contribute to infrastructure/overhead costs associated with delivering those goods or services and to support institutional needs and budgetary responsibilities.

The IRS assessment on academic units was created to recognize that these units should share in providing the resources for allocating funds to meet institutional needs and budgetary responsibilities. This recognition became important as implementation of Incentives for Managed Growth resulted in a shift of unrestricted resources from central administration to academic units."

APPENDIX B

Table 3. Seed orchards currently managed by the Minnesota Tree Improvement Cooperative.

Species	Orchard Type	Organization	Planting	Date Planted	Size (ac)	Live Trees
Black spruce	First Generation Seedling Seed	Blandin Paper Co.	Blackberry	5/22/1978	2.5	596
Black spruce	First Generation Clonal	Koochiching Co.	Big Falls	5/19/1989	2.3	61
Black spruce	First Generation Clonal	Koochiching Co.	Larsaybow	5/27/1998	4	52
Black spruce	First Generation Seedling Seed	Minnesota DNR	Eaglehead	5/17/1978	2.7	582
Black spruce	First Generation Clonal	Minnesota DNR	Sturgeon Lake	5/1/1979	1.3	1624
Black spruce	Second Generation Full Sib	Minnesota DNR	Split Rock	5/27/1992	2.4	262
Black spruce	First Generation Seedling Seed	Potlatch Corp.	Cloquet	5/1/1978	3	580
Jack pine	Second Generation Full Sib	Crow Wing Co./MN DNR	County Line	5/1/1999	2.6	1705
Jack pine	First Generation Seedling Seed	Crow Wing County	Crow Wing	6/4/1985	2.1	320
Jack pine	First Generation Seedling Seed	IRRR Agency	Calumet	9/16/1982	1.7	220
Jack pine	First Generation Seedling Seed	Minnesota DNR	Longprairie	5/18/1984	4	495
Jack pine	First Generation Seedling Seed	Minnesota DNR	Nickerson	5/15/1984	2.4	403
Jack pine	First Generation Seedling Seed	Potlatch Corp.	Gillogly Rd.	6/28/1983	5.5	183
Jack pine	First Generation Seedling Seed	Red Lake Nation	Red Lake	4/29/1987	1.8	960
Jack pine	First Generation Seedling Seed	St. Louis County	Ellsburg Rd.	5/10/1988	1.6	280
Jack pine	Second Generation Full Sib	St. Louis County/IRRRB	Ellsburg Rd. East	5/12/1999	3.78	2574
Jack pine	First Generation Seedling Seed	Wausau-Mosinee Paper Corp.	Barnes	5/27/1988	4.1	549
Norway spruce	First Generation Clonal	Blandin Paper Co.	College S.O.	5/23/2001	0.55	152
Red pine	First Generation Seedling Seed	Cass/Beltrami/Hubbard Co.	Blind Lake	9/10/1991	5.3	2249
Red pine	First Generation Seedling Seed	Minnesota DNR	Cotton	7/29/1981	4.5	466
Red pine	First Generation Seedling Seed	Minnesota DNR	Eaglehead	6/25/1981	3.6	390
Red pine	First Generation Seedling Seed	Plum Creek Timber Co.	Ashwabay	9/17/1985	5.5	401

Red pine	First Generation Seedling Seed	Plum Creek Timber Co.	Petenwell	4/24/1990	5.5	1576
Red pine	First Generation Seedling Seed	Potlatch Corp.	Gillogly Rd.	7/10/1981	6.6	586
Red pine	First Generation Seedling Seed	St. Louis County	Ellsburg Rd.	5/9/1988	5.5	557
Red pine	First Generation Seedling Seed	Wausau-Mosinee	Mosinee	5/23/1990	5.7	1174
White pine	First Generation Clonal	Minnesota DNR	St. Francis	5/15/1985	3	318
White pine	First Generation Clonal	Rajala/Itasca County	Bass Lake	5/19/1998	5.7	498
White pine	First Generation Clonal	St. Louis County	Ellsburg Rd.	5/2/1990	1.1	233
White pine	First Generation Clonal	St. Louis County	Ellsburg Rd. East	6/21/1999	2.5	245
White spruce	First Generation Seedling Seed	Blandin Paper Co.	Latimer	5/15/1967	4.1	224
White spruce	First Generation Clonal	Blandin Paper Co.	Arbo	5/1/1976	1.5	121
White spruce	First Generation Clonal	Blandin Paper Co.	College	9/5/2000	2.9	628
White spruce	First Generation Clonal	Itasca County	Fig. Eight Lake	9/2/1987	1.1	187
White Spruce	Second Generation Full Sib	Itasca County	Wabana Lake	5/20/2003	1.8	784
White spruce	First Generation Clonal	Lake County	Two Harbors	9/2/1987	1	177
White spruce	First Generation Clonal	Minnesota DNR	Cotton	5/1/1977	12	206
white spruce	Second Generation Full Sib	Minnesota DNR	Eaglehead	6/3/2003	1.8	784
White spruce	First Generation Clonal	Potlatch Corp.	Cloquet	5/1/1977	3.3	140
White spruce	First Generation Clonal	St. Louis County	Ellsburg Rd.	5/11/1988	1.5	212
White Spruce	Second Generation Full Sib	St. Louis County	Ellsburg Rd. East	6/6/2003	2.1	896

APPENDIX C

Fifth year field measurements of jack pine second-generation population

Introduction

The need to progress into second-generation material led the Minnesota Tree Improvement Cooperative to begin an extensive breeding program of jack pine. Breeding work began in 1993 and was completed in 1997. In all, over two hundred full-sib, unrelated crosses were produced from five different seedling-seed orchards across Minnesota. Seed was stored until all crosses were completed. In 1998, seed was germinated at IRR greenhouse, and seedlings were out-planted in May 1999 at two sites, one each in St. Louis Co. and Crow Wing Co. Sites were planted as a randomized complete block design with single-tree plots.

Methods

In 2001 (after three growing seasons in the field), tree heights were measured to the nearest centimeter using a height pole. In 2003, in addition to tree heights, tree diameters (outside bark) at breast height (1.3 meters) were measured using calipers to the nearest millimeter. Data collected in 2003 also included stem straightness (stem form) and the incidence of gall rust (*Cronartium quercuum* or *Cronartium harnessii*). Stem form was assessed on a scale of 1-6 using a key provided by the New Brunswick Tree Improvement Council (Fullarton, 2001). The scale for stem form was as follows:

1 = Very much crooked in two planes
2 = Very much crooked in one plane or considerable crook in two planes
3 = Considerable crook in one plane or moderate crook in two planes.
4 = Moderate crook in one plane or slight crook in two planes
5 = Slight crook in one plane only
6 = No crook or very slight crook in one plane only

The incidence of gall rust was evaluated on a scale of 1-3 based on the number and severity of galls. The scale for gall rust evaluation was as follows:

1 = at least one gall on a lateral stem

2 = at least one gall on a main stem, or >3 lateral galls

3 = breakage/mortality due to stem gall

Tree volumes were calculated in cubic decimeters (dm^3) with the equation:

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

Individual tree measurements were transformed to remove the environmental effects due to blocking. Subsequent analysis of variance was used to test significance using the model:

$$Y_{ijkl} = \mu + S_j + F_k + S_j F_k + \varepsilon_l$$

where Y is total tree height, volume, stem form, or rust, μ is the overall mean, S_j and F_k are the effects of Site (St. Louis vs Crow Wing) and Family (1 - 100), respectively and ε_m is the experimental error. Variance components were found using the Type 1 method in SAS (1999) for each site using the model:

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

where Y is total tree height, diameter, volume, stem form, or rust, μ is the overall mean, R_j and F_k are the effects of replication (18 reps), and family (1 - 100), respectively and ε_l is the experimental error. Family (H^2_f) and individual (h^2_i) tree heritabilities were calculated for all traits at each site using the equations:

$$H_f^2 = \frac{\sigma_F^2}{\sigma_F^2 + \frac{\sigma_\varepsilon^2}{R}}$$

$$h_i^2 = \frac{(2)\sigma_F^2}{\sigma_F^2 + \sigma_\varepsilon^2}$$

where σ_F^2 is the variation due to family and σ_ε^2 is the remainder of the genetic variation plus variation due to experimental error and R is the number of replications. Average family scores for rust and stem straightness from the St. Louis Co. site were regressed on the Crow Wing Co. site to view correlations across sites.

Results

Survival at both sites was excellent, exceeding 90%. Site means and maximum values for heights and diameters are shown in Table 1 for 2001 (three year data) and 2003 (five year data). Heights and diameters were generally larger at Crow Wing than at St. Louis.

Table 1. Survival, average and maximum heights and diameters of jack pine at Crow Wing / MN DNR (CW) and at St Louis/IRR (St L).

	Survival		Avg Height (meters)		Avg DBH (cm)	Max	Max
Site	**2001**	**2003**	**2001**	**2003**	**2003**	**Height (m)**	**DBH (cm)**
CW	95%	92%	1.16	2.17	2.12	3.40	4.90
St L	92%	91%	0.83	1.97	1.75	2.90	3.80

Individual and family heritabilities were low for height, diameter, volume, and rust but were moderate for stem form (Table 2). Heritabilities were larger at Crow Wing than St. Louis for all variables.

Table 2. Individual and Family Heritabilities for Crow Wing/DNR (CW) and St. Louis/IRR (St L) sites.

	Individual		Family	
Site	**CW**	**St L**	**CW**	**St L**
Height 2003	0.10	0.07	0.47	0.37
DBH 2003	0.11	0.04	0.48	0.24
Volume 2003	0.08	0.04	0.42	0.26
Height 2001	0.16	0.09	0.58	0.43
Form	0.30	0.26	0.74	0.71
Rust	0.19	0.03	0.63	0.20

For all variables (adjusted for block effects), the “Site” factor was not significant, and differences among families were always highly significant (Table 3). The most interesting result is the Site*family interaction which was highly significant for rust, significant for height and volume, and not significant for stem form (Table 3).

Table 3. Significance of ANOVA F-statistic (p-values) for tree volumes, heights (Ht), stem form, and gall rust. Values with * are significant at $\alpha = 0.05$, ** are significant at $\alpha = 0.01$.

		Significance of F statistic			
Source	**DF**	**Volume**	**Ht**	**Form**	**Rust**
Site	1	0.258	0.3151	0.2614	0.6574
FAMILY	99	** <.0001	** <.0001	** <.0001	** <.0001
Site*FAMILY	99	* 0.0386	* 0.0163	0.1061	** <.0001

To investigate these interactions further, a correlation analysis was performed. With this analysis, family means are plotted and the linear relationship of the points is calculated as a correlation coefficient (a number between 0-1). This allows the actual distribution of family means to be graphically represented. The correlations for stem form were moderate, with an r-value of 0.66 (Table 4, Figure 1). Correlations for tree heights and volumes were weaker with r-scores of 0.31 and 0.28, respectively (Table 4, Figures 2-3). Since gall rust had a highly significant site*family interaction in the analysis of variance, it was not included in the correlation analysis.

Table 4. Correlation coefficients and significance for each variable.

Trait	r	p value
Stem Form	0.66	0.0001
Height	0.31	0.002
Volume	0.28	0.004

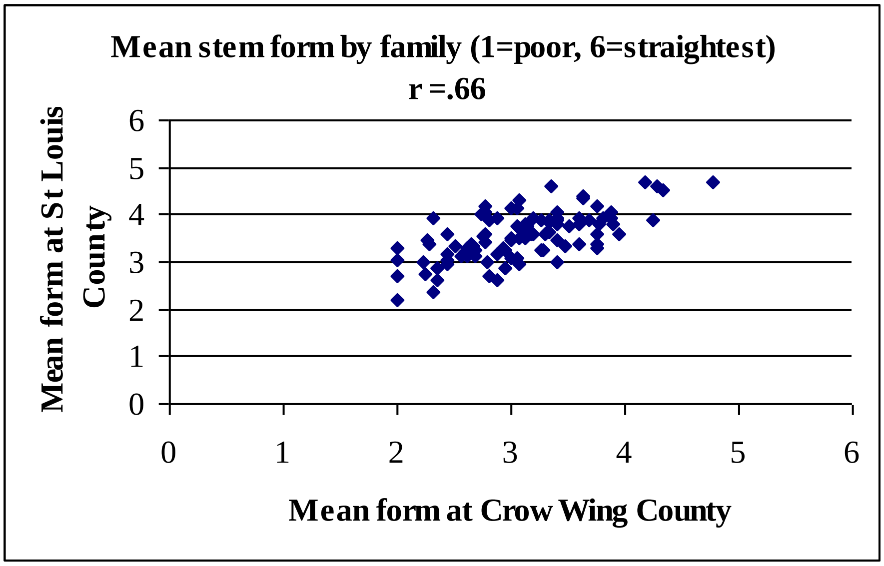

Figure 1. Mean stem form by family plotted for Crow Wing (x axis) and St. Louis County (y-axis).

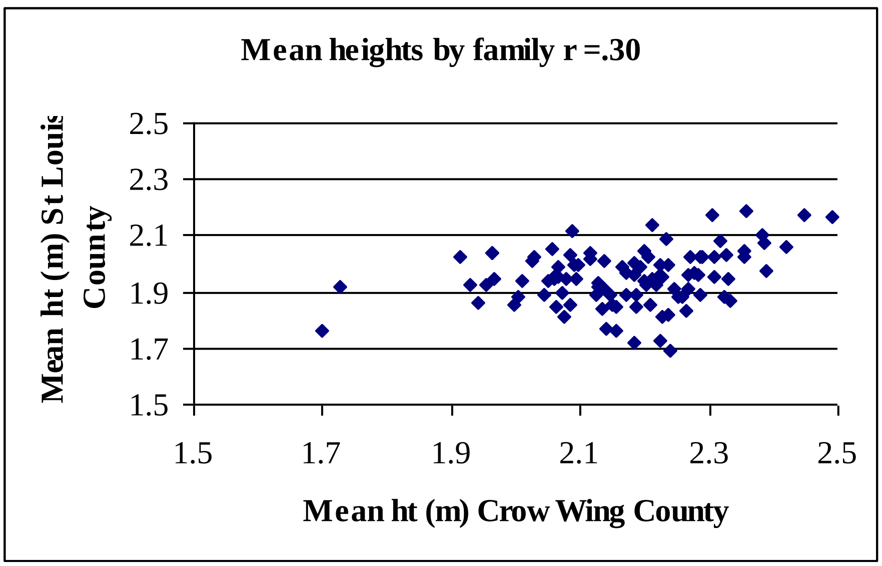

Figure 2. Mean height (meters) by family plotted for Crow Wing (x axis) and St. Louis County (y-axis).

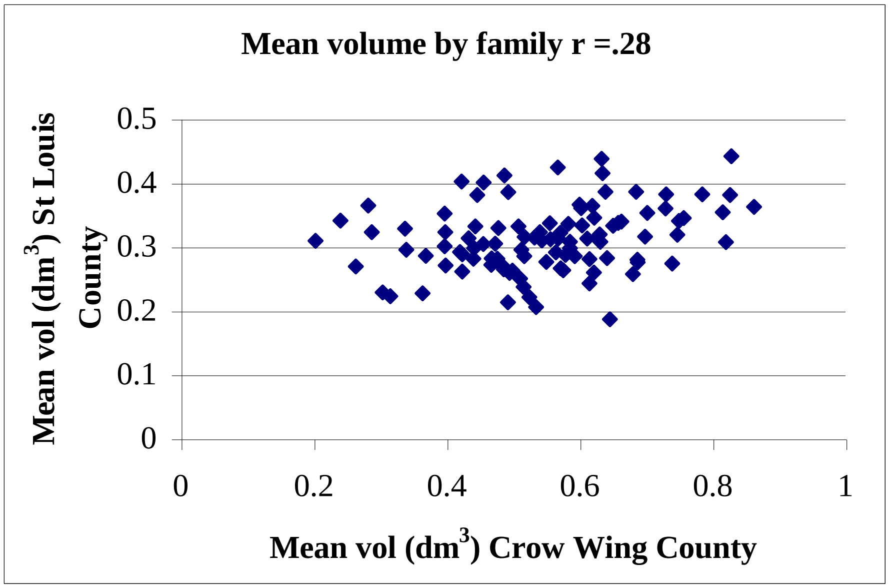

Figure 3. Mean volume (cubic decimeters) by family plotted for Crow Wing (x axis) and St. Louis County (y-axis).

Discussion

Survival at both sites was high. The topography at St. Louis County was slightly more variable within the site, and some mortality and reduced growth was observed in low-lying areas. Most mortality at Crow Wing could be attributed to root pruning by the plains pocket gopher (*Geomys bursarius*). Efforts to control the pocket gopher included disking between rows repeatedly throughout the growing season, as well as poisoning tunnels. Control efforts appear to be partially successful.

Significant differences among family means for all variables were expected since families were unrelated full-sibs. Differences between sites were significant with raw, unadjusted data (not shown). After transforming the individual tree values to remove environmental block effects, differences between sites became negligible. The site*family interactions are a measure of consistency of performance, that is, whether top-performing families at one site were also top-performers at the other site. Although the interaction was significant for tree heights and volumes, the differences were relatively small, and may become insignificant with future measurements.

Heritability estimates for 2003 heights and diameters were relatively low, but not unexpectedly low for full-sib data. Riemenschneider reported heritabilities for five-year heights for jack pine half-sibs of 0.21 (1988) and 0.105 (1979), which are higher than the current study (0.04, St Louis; 0.10, Crow Wing). Variability within families tends to be lower in full-sibs, as they are more genetically alike than half sibs. Since the family variance (σ^2_f) resides in the numerator of the heritability equation, the overall heritability decreases when σ^2_f decreases. The greater environmental variability at St. Louis County vs Crow Wing County is likely the cause of the smaller heritabilities at St. Louis. It should be noted that heritabilities are very sensitive to environmental effects, and have a high degree of error. The heritabilities will likely change with subsequent measurement data.

Gall rust occurrence was vastly different at the two sites, rendering the site*family interaction highly significant. A highly significant interaction indicates that family means did not perform consistently between sites. This was not surprising since the infection type and severity varied greatly between the sites. Trees at Crow Wing were infected with small, numerous galls on lateral stems that rarely posed a threat to the tree's survival. In contrast, rust on trees at St. Louis County was frequently evident as a single large gall on the main stem, causing premature breakage and mortality in several cases. It is possible that different species of rust are present at the different sites, or that the seedlings at St. Louis Co. were infected at a younger age. Gall rust incidence will be observed in subsequent measurements and accounted for in future selections.

Wood quality traits are frequently under moderate to strong genetic control, which corroborates well with the observed stem form data. Despite this expectation, it was surprising that the small stature and obvious plasticity of the stems would yield such measurable correlations. It is possible that these correlations will even increase as stems lignify and strengthen. Because of the moderate heritability associated with stem form, it will be weighed heavily in future selections. Branch angle is another wood quality trait worth estimating in the future, and will also likely show moderate heritabilities. At this measurement period, the small stature of the trees made branch angle assignments impossible, but this trait should be easier to observe on larger trees.

At eight years after planting both sites will be re-measured, and a breeding value assigned to each tree. These values will be a composite of all three variables (volume, stem form and gall rust), after each is weighed according to its heritability at the site. After breeding values are assigned, a percentage of individuals with low breeding values may be rogued at that time as well. Test-crosses can begin as soon as 2004 if flowers are available.

References

Fullarton, Michele. 2001. "Genetic Field Test Handbook, NBTIC Guidelines." Fredericton, NB. 44 p.

Riemenschneider, Don E. 1979. Genetic variation and predicted response to selection for height in a north-central MN population of jack pine (*Pinus banksiana*, Lamb.). St Paul, MN. PhD Thesis. 76p.

Riemenschneider, Don E. 1988. Heritability, age-age correlations, and inferences regarding juvenile selection in jack pine. Forest Science, 34(4): 1076-1082.

SAS Institute, 1999. Cary, NC. Version 8.01.

APPENDIX D

PROGRESS REPORT: Testing Suitable Sources of White Spruce Seedlings for Underplanting in Shelterwood Situations

Sarah Worrall, MS Candidate

Introduction

After white spruce (*Picea glauca*) are harvested there are two ways for regeneration of the stand to occur, one is by planting seedlings and the second is through natural regeneration. The shelterwood silvicultural system involves removing overstory trees in a series of harvests that are spaced several years apart. The residual trees provide a seed source for natural regeneration and serve to protect the understory from environmental extremes in temperature and wind. Shelterwood systems have been successful for regenerating shade-tolerant species such as white spruce under optimal regeneration conditions. However, lack of seed, lack of adequate bare mineral soil, and drought after seedling germination or establishment may result in unsuccessful regeneration. If regeneration does not occur on its own underplanting is necessary to ensure that adequate regeneration does occur.

Tree improvement programs evaluate planting stock based on how well it performs under open-grown conditions, so its performance under different levels of light, such as in an underplanting, is unknown. The purpose of this study is to test suitable sources of white spruce seedlings for underplanting in shelterwood situations. The study is broken down into two parts. The first part is an evaluation of white spruce seedlings growing under different levels of light in the understory of two stands in Northern Minnesota, one mainly hardwood stand and one mainly coniferous stand. The objective of this portion is to compare how the growth of white spruce differs under varying levels of light and under different types of overstory. In addition this portion will help determine at what levels of light the differences in growth of white spruce are most pronounced. This will determine the best light levels to use in the second part of the study. I have been working on this portion of the study over the past year. The second part of the study is a controlled seedling experiment where the growth of white spruce planting stock from different stages in the domestication process will be compared to the growth of unimproved planting stock under different levels of light. The seedlings will be grown under the levels of light determined in the first portion of this study. The objective of this portion is to determine the best planting stock to use under different light levels.

Methods

In the summer of 2003 two suitable sites for the field portion of this study were located in Itasca County. The first site, owned by Blandin Paper Company, consisted of an overstory of mainly trembling aspen with a limited number of large white spruce trees, paper birch, balsam fir, and red pine. In addition, this site contained a thick understory of hazel. The second site, owned by Itasca County, was a red pine plantation with a few white spruce, black spruce, jack pine, white pine, balsam fir, trembling aspen, paper birch, and balsam poplar present. At each site 160 white spruce seedlings were flagged and mapped. When possible, seedlings were chosen based on the appearance that they were growing under varying levels of light from one another.

In August, once growth had ceased and the current year's needles had matured, measurements of the seedlings were taken. The measurements included: overall height of the seedling, length of the leader, and diameter of the leader. Ground cover surrounding the seedling was also evaluated based on whether there were herbaceous plants, woody shrubs, grasses, moss, or bare ground present around the seedling. In addition, the basal area of the surrounding overstory was recorded. At this time the percent of sunlight reaching the seedlings was also measured with a ceptometer. The light measurements were only taken on overcast days so that sunflecks did not impact the readings.

Once these measurements were complete, histograms of the light data were made in order to organize which seedlings were growing under which levels of light. Seedlings were broken up into 5% intervals (0-5%, 5-10%, and so on) of light from 0-100%. Three seedlings from each 5% interval at both sites were chosen (or if less than 3 were in an interval all of the seedlings were used) to take samples from. In September, a lateral leader sample was removed from each of these seedlings and kept refrigerated for further analysis.

Analysis of the samples was completed in the fall of 2003. The analysis included: counting the needles present on a 1 cm area of each of the samples and determining the specific leaf area (SLA) of 3 needles per sample. The SLA was determined using the glass bead technique. The data analysis of this portion of the study is currently being worked on.

APPENDIX E

PROGRESS REPORT: University of Minnesota White Pine Blister Rust (*Cronartium ribicola*) Screening Project

R.A. Blanchette, T.A. Burnes, J. A. Smith and J.A. Jurgens
Department of Plant Pathology, University of Minnesota
495 Borlaug Hall, 1991 Upper Buford Circle
St. Paul, Minnesota 55108-6030

White pine blister rust is caused by *Cronartium ribicola*, an introduced fungus that has caused devastating losses to white pine over the past 100 years. The rust has two hosts 5 needle pines and currants/gooseberries (*Ribes* spp.). On pines, the fungus cause stem and branch cankers that result in tree death. Infection occurs by basidiospores that are produced on leaves of infected *Ribes* spp. These spores are dispersed by wind currents and land on pine needles during late summer and early fall. During cool, moist conditions infection will take place through the stomata of the needles and a symptomatic spot (lesion) will develop. Needle lesions continue to develop during the next growing season and the infection may develop into the stem tissue of the shoot. Once in the shoot, the fungus will continue to invade stem tissue until the main bole is girdled. A few years after infection, the fungus produces the characteristic blisters which produce the aeciospores that are released in early summer and infect the *Ribes* spp. After several cycles of infection on the *Ribes* by urediniospores, telia are formed that give rise to basidiospores and the cycle is completed.

Screening for resistance to white pine blister rust in seedlings from controlled-crosses and open pollinated trees of eastern white pine selections from The United States Forest Service, Oconto River Seed Orchard were conducted. Screening was done by placing leaves of *Ribes nigra* infected plants over 12 week-old white pine (greenhouse grown) seedlings inside an environmentally controlled chamber. Four weeks after infection, characteristic chlorotic spots form on needles that have become infected. Data is collected on the number of infections (spots) that are formed four weeks after inoculation and data on mortality is collected every two weeks for 52 weeks (Table 1). Screening has been done on 23 seed lots from Oconto Seed Orchard and two from Minnesota families. Additionally, 22 seed lots are currently being screened.

In addition to the screening investigations, studies have been done to determine if morphological characteristics of the needle (needle topography, epistomatal waxes, etc.) contribute to blister rust resistance. Scanning electron microscopy and inoculations of needles with and without epistomatal wax is being used to document the effect of wax occlusion of stomata on blister rust infection. Additionally, quantitative and qualitative features of the wax are being assessed by gas chromatography/mass spectrometry to investigate potential antimicrobial compounds in the waxes from resistant white pine families.

Research findings from histological studies resistant and susceptible reactions in seedlings is continuing. Recent findings were published in the journal *Plant Disease* (see reference below – a reprint of this paper is available on the web at http://www.plpa.agri.umn.edu/~robertb/pdfreprints/whitepineblisterrust.pdf). An oral presentation on these studies was also given at the North Central Forest Pest Workshop in Cloquet, MN in September, 2003.

Future research will focus on 1) screening white pine material grown at the Tofte, Minnesota site (Ahlgren selections) and possibly other native Minnesota seed sources, 2) histology of the interactions between host and pathogen (including stem reactions to infection) and 3) additional studies on the importance of epistomatal waxes on needle surfaces as a mechanism for resistance. These results will continue to provide useful information that will be used in efforts to select and develop eastern white pine with enhanced resistance to this destructive pathogen. For more information on our current white pine blister rust research activities visit: http://forestpathology.coafes.umn.edu/whitepine.htm

Table 1.
Results from a selection of eastern white pine screened for white pine blister rust

White Pine Families	Weeks to reach 50 %mortality	Average needle spot index* four weeks after inoculation
H111	22	3.0
343 X H109	26	2.1
343 X 343	26	2.7
327 X 312	No mortality	1.9
312 X 327	27	1.5
327 X H109	40	1.2

*Index numbers for the number of needle spots per seedling inoculated four weeks after inoculation: 1=1-3 spots, 2=4-10 spots, 3=11-32 spots, 4=33-100 spots, 5=101-316, and 6=317-1000 spots.

Publications

Jurgens, J.A., Blanchette, R. A., Zambino. P. J. and David, A. J. 2003. Histology of resistance mechanisms to white pine blister rust in needles of eastern white pine. Plant Disease 87: 1026-1030.

Smith, J.A. and J.F. Gillman. 2002. White pine blister rust: an introduced disease of pines and currents. Minnesota Nursery Growers Bulletin. April 2002.

Jason A. Smith, Todd A. Burnes, Joel A. Jurgens, Andrew J. David, and Robert A. Blanchette. 2002. Potential resistance mechanisms in *Pinus strobus* L. to infection by *Cronartium ribicola* J. C. Fisch. ex Rabenh. Proceedings of IUFRO Rusts of Forest Disease Conference, Yangling China.

IMAGES FROM 2003

Minnesota Tree Improvement Cooperative

2003 ADVISORY COMMITTEE

FULL MEMBERS	
Beltrami County	Greg Snyder, Bob Milne
UPM-Kymmene Blandin Paper Company	Gene Grell, Jim Marshall
Cass County	Mike Wadman
Crow Wing County	Bryan Pike, Tom Cowell
Plum Creek Timber Company	Joel Aanensen
Iron Range Resources, Mineland Reclamation	Dan Jordan
Itasca County	Mike Gibbons
Itasca Greenhouse Inc.	Bill Sayward, Quintin Legler
Koochiching County	Tim Probst, Tom Morris
Lake County	Bill Nixon
Minnesota DNR - Forestry	Rick Klevorn
Potlatch Corporation	Mike Fasteland
Red Lake Nation	Gloria Spears, Bob Lintelmann
St. Louis County	Mark Pannkuk
Univ. of Minnesota Dept. of Forest Resources	Alan Ek
Wausau-Mosinee Paper Corp.	Pat Scheller
SUPPORTING MEMBERS	
Carlton County	Milo Rasmussen
Clearwater County	Bruce Cox
Hedstrom Lumber Co.	Howard Hedstrom
Hubbard Co.	Allen Lysdahl
Pine County	Greg Beck
Rajala Companies	Beth Jacqmain